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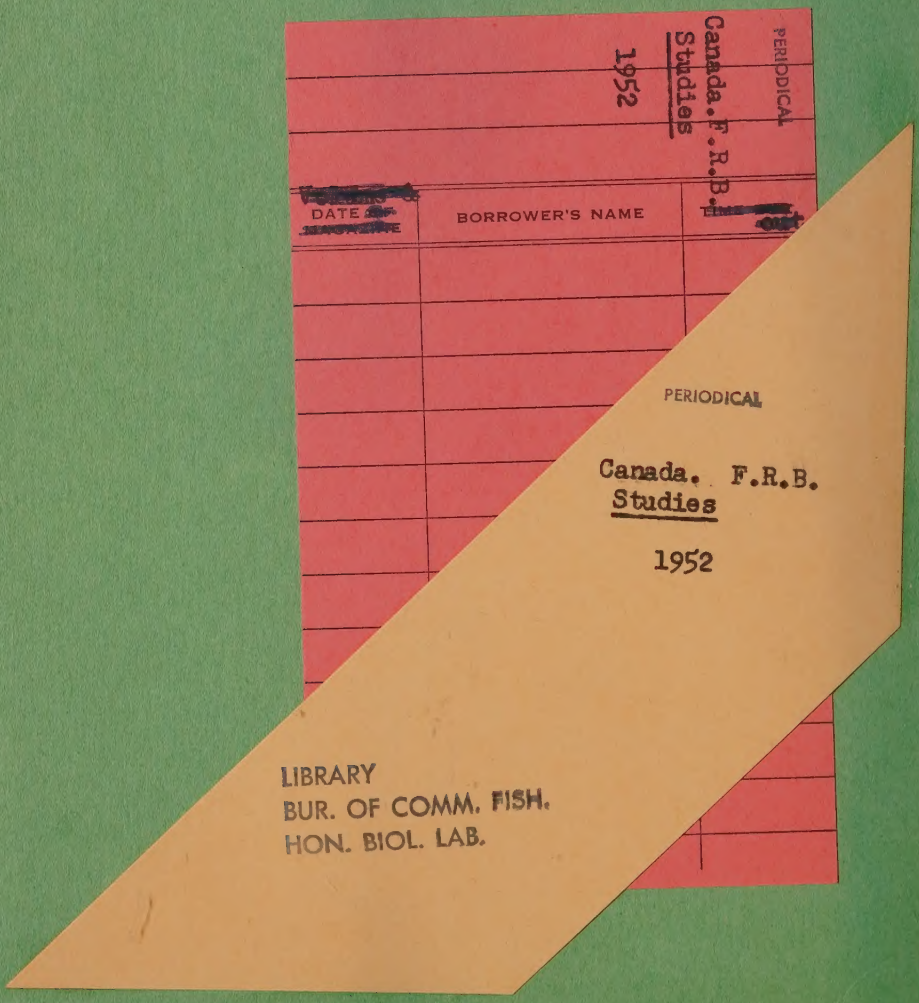
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RESULTS OF THE WEST COAST OF VANCOUVER ISLAND HERRING INVESTIGATION, 1950–51

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INTRODUCTION

In 1946–47 and in subsequent seasons the west coast of Vancouver Island herring population has been subjected, in so far as possible, to unrestricted fishing, except for a closure date prior to spawning. During the same period, another herring population, that of the lower east coast of Vancouver Island, has been fished under identical regulations, except that the catch has not been allowed to exceed 40,000 tons annually. The practical object of the plan was to permit scientific investigation of the two populations in order to determine whether catch quotas are effective in stabilizing herring populations or whether they are unnecessarily restrictive in view of the large natural fluctuations known to occur in population abundance.

In the early years of the study a broad and intensive research programme was developed, and its continuance is planned for a period of years through various levels of population abundance. The annual programme aims specifically at accurate collection of catch statistics, determination of the relative strengths of year-classes supplying the fishery, investigation of extent of movement between the two populations and relative amount of interchange with other herring populations of the British Columbia coast, and estimation of the relative size of the spawning runs. Also, certain population statistics are calculated on the west coast stocks. In addition to these studies on the adult fishable populations, a study of factors influencing survival during the early life-history is being

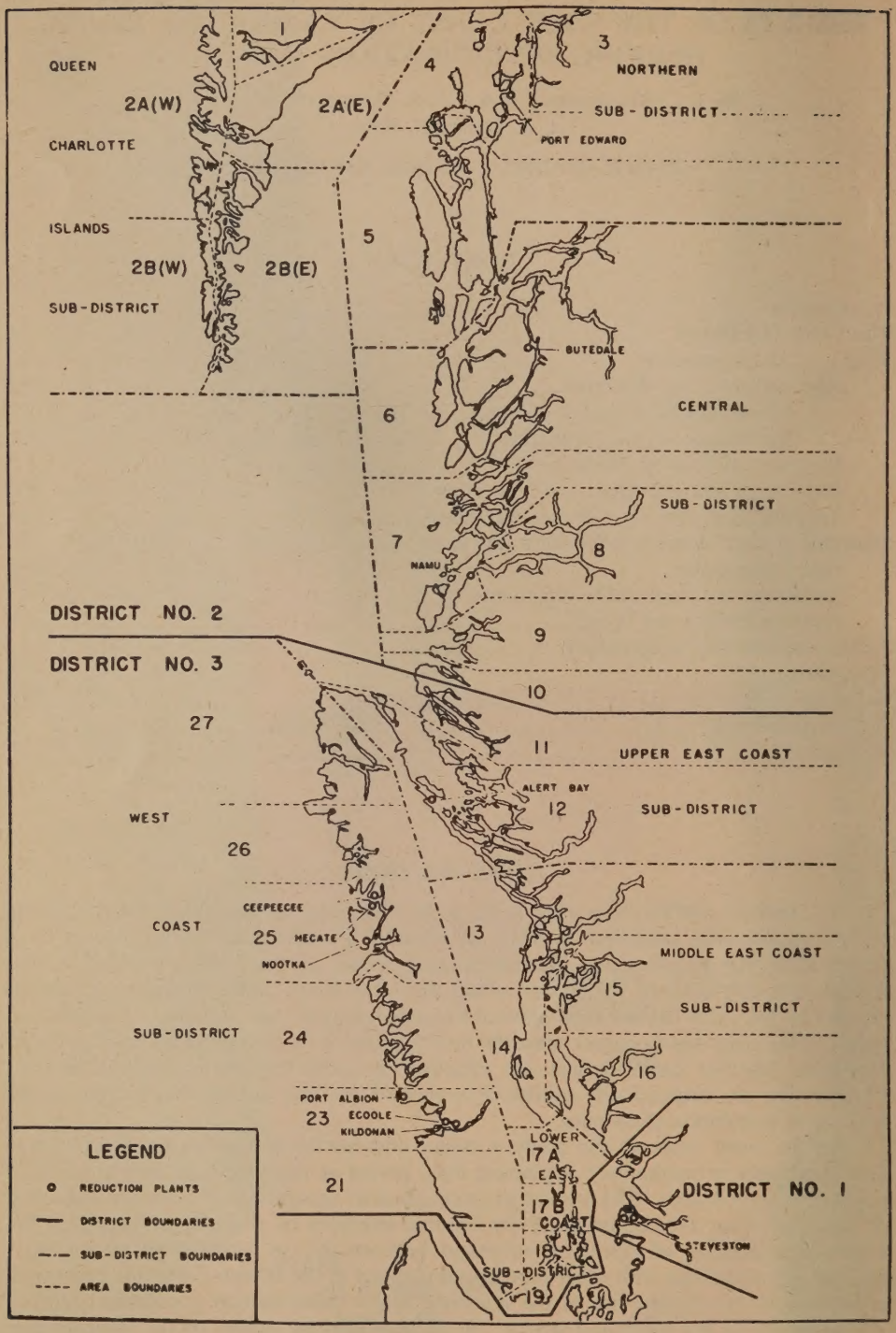

Fig. 1. Map showing the division of the British Columbia coast into districts, sub-districts, and areas.

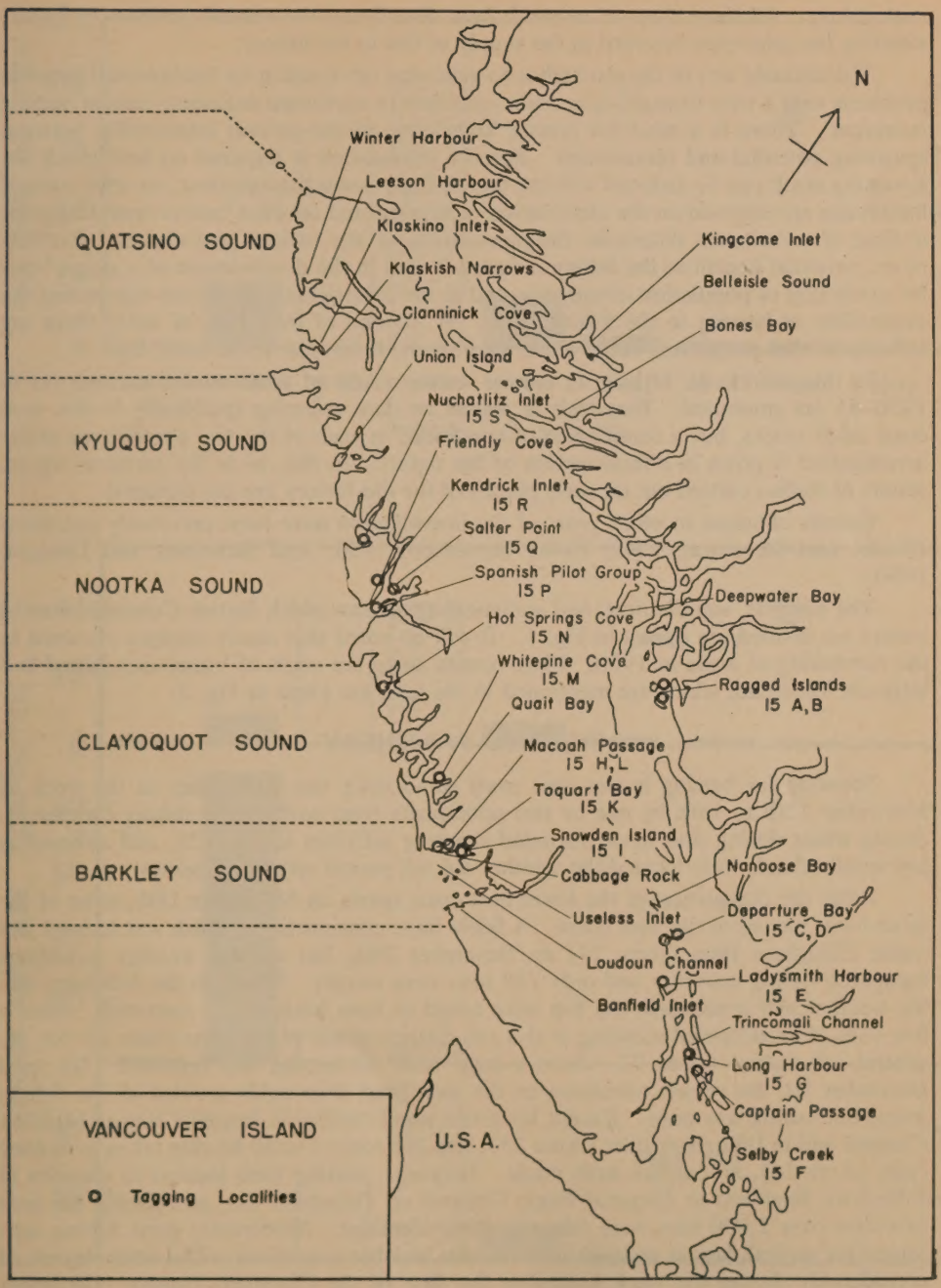

Fig. 2. Map of Southern British Columbia showing the location of places mentioned in the text.

undertaken. All these lines of research bear directly on the central problem of understanding the principles involved in the supply of fish to the fishery.

The ultimate aim of the research is to gain vital information on fundamental fisheries problems with a view to enabling a closer approach to maximum sustained yield of herring resources. There is a need for greater knowledge of the general relationship between spawning potential and recruitment. Specific information is required on how much the spawning stock can be reduced without decreasing eventual recruitment, on what natural limitations are imposed on the exploitation of herring, and on what factors operating prior to time of recruitment determine the productivity of the various year-classes. Furthermore, potential benefit to the fishing industry is seen in the development of a sound basis for prediction of population abundance, and in the investigation of factors influencing the availability of herring to the fishing fleet. At the end of five years of study there are indications that progress is being made towards the fulfilment of the basic aims.

In this report, the fifth in an annual series, results of adult studies carried out in 1950–51 are presented. Emphasis is placed on data referring specifically to the west coast adult stocks, but a comparison of conditions in each of the two populations under investigation is given in a final section of the report. In this, as in the previous report, results of studies carried out on early phases of the life-history are not included.

Results obtained in other years of the investigation have been previously published (Tester and Stevenson, 1947, 1948; Stevenson, 1950; and Stevenson and Lanigan, 1950).

The districts, sub-districts, and statistical areas into which British Columbia coastal waters are divided are shown in Fig. 1. It will be noted that minor changes occurred in the numbering of areas in 1950. Place-names along the coast of Vancouver Island and adjacent Mainland, which are mentioned in the text, are given in Fig. 2.

THE 1950–51 FISHERY

Scouting for herring in the west coast sub-district was undertaken in the week of November 12th to 18th by one or two seine-boats from each of the fishing companies. Strong winds during that week restricted scouting activities to Area 23, and although a few small schools were located the weather did not permit setting the seines.

After the completion of the lower east coast quota on November 19th, most of the seine-boats moved to the west coast. A fairly large concentration of fish was located just inside Effingham Inlet (Area 23) on November 20th, but adverse weather conditions hampered fishing activities and only 130 tons were caught. When on the following day the weather had moderated, the fish were found to have been widely scattered. After a few days of unsuccessful scouting in this sub-district, many of the seine-boats left for the central sub-district (Area 7), where a large body of herring was reported. Up until December 1st, the vessels remaining on the west coast thoroughly scouted all the fishing areas, but fishing was poor. Except for a few small catches in Imperial Eagle (Middle) Channel and in Effingham Inlet (Area 23), and 365 tons of small herring taken in Sydney Inlet (Area 24), no catches were made. However, herring were located in quantity in Effingham Inlet and in Imperial Eagle Channel on December 1st, and during the next two days over 2,000 tons were taken in those localities. Moderately good fishing continued for several days in spite of unfavourable weather conditions. The catch decreased considerably during the week preceding the date of the Christmas closure (December 15th), partly because of the decreased fishing effort which resulted when most of the west coast fishing-vessels were moved to the northern sub-district to take part in the large Ogden Channel fishery (Area 5). The pre-Christmas west coast catch totalled approximately 9,250 tons, less than half that obtained for the corresponding period in the previous season.

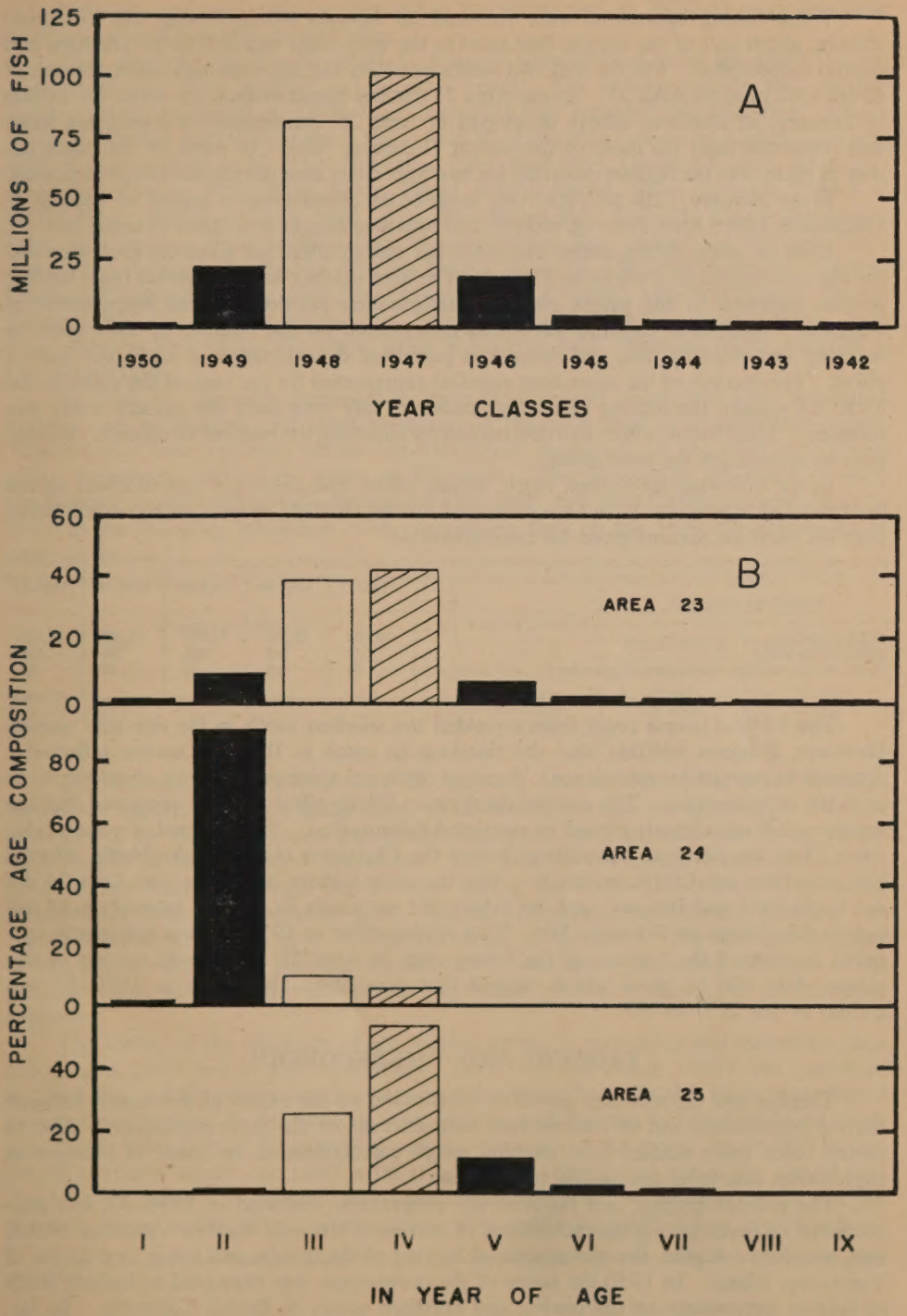

Fig. 3. Diagrams showing the total number of herring in each year-class caught by the commercial fishery in 1950–51 (A), and the average percentage age composition of samples from the commercial catches in Areas 23, 24, and 25 (B).

When fishing operations were resumed on January 4th following the Christmas closure, about half of the seining fleet went to the west coast and half to the northern and central sub-districts. For the first two weeks excellent fishing, with high catch per unit of effort, took place in Area 23. As the Area 23 catches began to decrease about the middle of January, an intensive fishery developed in Area 25, particularly in Esperanza Inlet, and continued until the close of the season (February 5th). In Area 25 the catch per unit of effort was the highest recorded for any west coast area during the 1950–51 season.

From January 11th to 19th, two seine-boats investigated a report of herring in Ououkinsh Inlet (Area 26). A total of 250 tons was caught in a series of small sets.

Data on catch, fishing effort, and catch per unit of effort are given for each area and for the sub-district as a whole in Table I. The area catches were estimated from landing records supplied by the plants and from information provided by the Department of Fisheries. Seine-boat captains submitted information on the number of days spent in scouting and catching fish, and these data permitted determination of catch per unit of effort. The records of the seine-boat captains represented 89 per cent of the catch in the 1950–51 season, the highest percentage return of any year since the present study was initiated. Total fishing effort was determined by adjusting the number of recorded fishing-days to account for the total catch.

In the following tabulation, catch, fishing effort, and catch per unit of effort on the west coast of Vancouver Island are presented for the 1950–51 season, with corresponding data for previous seasons given for comparison:—

	1946–47	1947–48	1948–49	1949–50	1950–51
Catch (tons)	59,000	45,200	55,000	37,300	25,200
Effort (seine-days)	777	948	686	790	528
Catch per unit of effort (tons per seine per day)	76	48	80	47	48

The 1950–51 west coast fishery yielded the smallest catch in the five-year period. However, it seems unlikely that the decrease in catch in the past season reflected a decrease in population abundance. Average catch per seine per day was about the same as in the previous year. The marked decrease in fishing effort strongly suggested that the smaller catch was directly caused by restricted fishing effort. The removal of vessels from Area 23 to the northern sub-district before the Christmas closure undoubtedly affected the size of the pre-Christmas catch. Also the main inshore migration into Area 25 did not begin until mid-January, and the fishery did not reach its greatest intensity until just before the closure on February 5th. Thus fishing effort in 1950–51 was apparently curtailed because of the lateness of the fishing runs in Area 25. In a later section of this report, data will be given which suggest that population abundance in 1950–51 was similar to that in 1949–50.

TAGGING AND TAG-RECOVERY

Tagging and tag-recovery provides information on the extent of movement between herring populations and of intermixture between runs of the same population. Also in recent years these studies have enabled rough calculations to be made of changes in exploitation rate from one season to the next.

The present tagging and tag-recovery programme, initiated in 1946–47, has concentrated on investigating the movements of herring of the west coast of Vancouer Island, and, to a lesser degree, the movements of herring of the middle and lower east coasts of Vancouver Island. In 1950 the scope of the programme was expanded to include study of herring movements on the central and northern coasts of British Columbia. So far, estimations of changes in exploitation rates have been made on only the west coast of Vancouver Island population.

Methods used in tagging herring and in recovering tags in 1950–51 were the same as those employed in the previous year.

Tags recovered during the 1950–51 fishery* were derived from the 1950 tagging (14-series) and from taggings of previous years. The fishing-grounds that yielded catches which contained or might have contained tags included the following: (Area 2B (E)—Huxley Island, Sedgewick Bay; Area 4—Edye Pass; Area 5—Ogden Channel, Kitkatla; Area 6—Laredo Inlet, Helmcken Inlet, Surf Inlet, Gardner Canal; Area 7—Kwakshua Passage, Bella Bella, Spider Island, Kilidit Sound, Nalau Passage; Area 8—David Bay; Area 9—Moses Inlet; Area 12—Bones Bay, Belleisle Sound, Kingcome Inlet, Port Harvey, Bond Sound; Area 13—Deepwater Bay; Area 17A—Nanoose Bay; Area 17B—Trincomali Channel, Walker Rock; Area 18—Swanson Channel, Satellite Channel, Captain Passage; Area 23—Imperial Eagle Channel, Louden Channel, Trevor Channel, Peacock Channel, Mayne Bay, Effingham Inlet; Area 24—Sydney Inlet; Area 25A—Herring Bay; Area 25B—Port Eliza, Esperanza Inlet, Espinosa Inlet; Area 26—Ououkinsh Inlet.

In 1950–51, tags were recovered by three tag-detectors installed in plant unloading systems and by magnets and plant-machinery in the meal-lines of all reduction plants. Tag-detectors were operated at the Imperial plant, Steveston; at the Gulf of Georgia plant, Steveston; and at the plant at Kildonan. The percentage efficiency of each tag-detector in recovering tags during pre-Christmas and post-Christmas operations is given in the following tabulation, with comparable data on the 1949–50 efficiencies in parentheses:—

Detector Installation	Type of Detector	Operation on Catches	
		Pre-Christmas	Post-Christmas
Imperial	Old-type	90 (60)	71 (78)
Gulf of Georgia	New-type	25 (86)	94 (50)
Kildonan	Old-type	68 (—)	36 (—)

The decrease in the efficiency of the Imperial detector during the post-Christmas operations was the result of a faulty relay, which diminished detector sensitivity. The low efficiency of the Gulf of Georgia installation during the pre-Christmas period was attributed mainly to inexperienced operators. The average percentage efficiencies of the Imperial and Gulf of Georgia tag-detectors during the 1950–51 season did not differ greatly from those of the previous year. The performance of the Kildonan detector was considerably better than in 1949–50, its first season of operation. The reduced efficiency of this detector during the post-Christmas fisheries was due to increased vibration of the pick-up coil in the conveyor system, resulting from a general weakening of the conveyor supports.

The testing of the efficiency of the various plants in recovering and submitting tags found on magnets and in plant-machinery (Tester and Stevenson, 1948) was continued in 1950–51, and the programme was considerably expanded. Twelve plants were tested as compared to seven in the previous year, and the total number of individual tests made was almost twice that of the preceding season. Because of the recent resumption of tagging in northern waters, one plant in the northern sub-district and one in the central sub-district were tested. A comparison of percentage efficiency of recovery in the various plants is shown in the following tabulation, with results for 1949–50 in parentheses:—

* A list of the places and dates of the individual taggings which produced recoveries during 1950–51 will be supplied on request.

West Coast Plants

	Number of Tests	Average Percentage Recovery
Kildonan	2 (1)	88.0 (92.0)
Ecoole	1 (1)	90.0 (98.0)
Port Albion	2 (2)	91.0 (93.0)
Nootka	3 (2)	88.0 (68.0)
Ceepeecee	1 (..)	68.0 (.....)
Average of west coast plants		85.0 (87.8)

Steveston Plants

	Number of Tests	Average Percentage Recovery
Imperial	3 (2)	82.0 (79.6)
Gulf of Georgia	3 (2)	50.4 (58.2)
Colonial	3 (2)	73.7 (74.0)
Phoenix	1 (..)	86.0 (.....)
Average of Steveston plants		73.0 (70.6)

Other Plants

	Number of Tests	Average Percentage Recovery
North Shore (North Vancouver)	1 (..)	54.0 (.....)
Namu (central coast)	1 (..)	78.0 (.....)
Port Edward (northern coast)	1 (..)	78.0 (.....)
Average of other plants		70.0 (.....)
Grand average		77.3 (80.4)

Percentage efficiency of recovery was remarkably similar in the two seasons. Only one plant, Nootka, showed an appreciable change. The increase in efficiency of this plant was largely the result of improvements made to the rectifier which supplied direct current to the electromagnet. As in previous years most of the tags used in the tests were recovered during the first five days after the tests were conducted. Five tags were recovered from tests made in the previous season: One at Imperial, one at Colonial, and three at Nootka.

The ways in which knowledge of detector-efficiency and plant-efficiency aid in analysis of the tag-returns were outlined in the previous report of this series (Stevenson and Lanigan, 1950, p. 47).

Recoveries by Tag-detectors

During the 1950–51 herring fishery, 259 tags were recovered by the tag-detectors, as follows: Imperial, 146; Gulf of Georgia, 103; and Kildonan, 10. Two tags were taken from the northern sub-district catch, 111 from that of the central sub-district, 2 from the upper east coast, 26 from the lower east coast, 30 from the middle east coast, and 88 from the west coast. The number of detector-returns was 89 per cent greater than in the previous season. The increase was chiefly a result of the large tag-recovery in the central sub-district. Recoveries from the 1950 tagging in the central area comprised 42 per cent of the total detector-returns.

Another factor which contributed to the large recovery of tags was the apparently greater concentration of tags in the west coast population in 1950–51. It was calculated that in 1950–51 there were 0.0531 tags per ton of fish caught, whereas in the previous year there were 0.0205 tags per ton. Thus even though the west coast catch decreased

in the past season, the number of tags recovered was similar in each year. The increased concentration of tags in the west coast catches was partly attributed to the large west coast tagging in 1950, which resulted in the tagging of 22 per cent more fish than in the previous year (Stevenson and Lanigan, 1950).

Movement between Populations

The probable number of tags in the various catches was calculated from the actual number of tags recovered, by considering detector-efficiency and by correcting for the fact that only part of the catches was examined by tag-detectors. The actual numbers of tags recovered by detectors in 1950–51 and the calculated probable numbers of tags in the catches are given in Table II according to area of tagging, tagging code, and area of recovery. This table is summarized in the following tabulation, according to sub-districts, to provide pertinent data for the analysis of herring movements; the probable number of tags in the various catches are given, actual numbers of tags on which calculations are based are shown in parentheses, and additional information is given on probable concentrations of tags in the sub-district catches:—

Sub-district of Tagging	Sub-district of Recovery						
	Northern	Central	Upper East Coast	Middle East Coast	Lower East Coast	West Coast	Total
Northern	77 (2)	———	———	———	———	———	77 (2)
Central	———	859 (98)	———	———	———	17 (1)	876 (99)
Upper east coast	———	———	23 (2)	———	———	———	23 (2)
Middle east coast	———	———	———	161 (22)	3 (1)	17 (1)	181 (24)
Lower east coast	———	———	———	8 (2)	257 (21)	31 (2)	296 (25)
West coast	———	152 (13)	———	20 (2)	60 (8)	1,273 (84)	1,505 (107)
Totals	77 (2)	1,011 (111)	23 (2)	189 (26)	320 (30)	1,338 (88)	2,958 (259)
Catch (in tons)	50,650	51,300	3,900	12,050	41,050	25,200	—
Probable number tags per ton	0.0015	0.0197	0.0059	0.0157	0.0078	0.0531	

A large proportion of the tags (probable numbers) was recovered from the sub-district in which they were originally used. All of the northern and upper east coast tags which were recovered in 1950–51 came from catches made in their respective tagging sub-districts, and 98.1 per cent ($^{859}/_{876}$) of the central sub-district tags were taken from central catches. On the other hand, only 84.5 per cent ($^{1273}/_{1505}$) of the west coast tags were derived from west coast catches. Since the concentration of tags varied greatly in the various populations (probable number of tags per ton are given in above tabulation), it is obvious that the relative strength of the " homing " tendency in the different populations cannot be readily compared. The low concentration of tags in the northern and upper east coast sub-districts would be less liable to show extensive movement of tags from those regions than the higher concentration of tags in the central and west coast populations. Unknown differences in exploitation of the various populations further complicate the analysis. However, the data suggest that the proportion of the central herring which returned to the central sub-district in 1950–51 was appreciably greater than the proportion of west coast fish which returned to the west coast. In the previous season a similar percentage of west coast tags was recovered in west coast catches (88 per cent—Stevenson and Lanigan, 1950).

On the basis of detector-returns, the only sub-district to which central herring were known to have moved in 1950–51 was the west coast of Vancouver Island, the calculated extent of emigration amounting to 1.9 per cent ($^{17}/_{876}$). The percentage of west coast fish moving to the central sub-district was found to be 10.1 per cent ($^{152}/_{1505}$). From these calculations and the total sub-district catches, it was further computed that about 1,000 tons of central fish were caught on the west coast, and about 2,700 tons of west

coast fish were taken in central catches. If allowance was made for the fact that the more northerly section of the west coast population (Areas 25, 26, and 27) contributed all the west coast tags which were taken in the central catches (Table II), and for the fact that the more northerly part of the west coast population was more intensively tagged than the southern west coast runs, the amount of west coast fish taken in central catches was about 1,400 tons instead of 2,700 tons. Thus the amounts of herring which each population contributed to the catch of the other appeared to be similar. Many assumptions are involved in the above calculations, most important of which is that the tags are randomly distributed throughout the populations.

On the basis of tag-returns, it appears that most of the interchange of west coast and central herring took place in those portions of the populations which are geographically nearest each other. Area 7, where the major southern runs of the central sub-district are fished, contributed or received all tags involved in the interchange. Areas 25, 26, and 27, the most northerly west coast areas, contributed all the west coast tags which were returned from central catches. However, the single central tag taken on the west coast was taken in Area 23, the southernmost area of the sub-district. The latter exception to the generalization was considered the result of only one tag-return being involved.

The percentage movement of the west coast tags to the lower east coast (4.0 per cent—$^{60}/_{1505}$) was considerably smaller than in 1949–50, and similar to that calculated for the other seasons of the present study (Stevenson and Lanigan, 1950, p. 48). On the other hand, the movement of lower east coast tags to the west coast (10.5 per cent—$^{31}/_{296}$) was similar to that of the previous year. It was determined that about 900 tons of west coast fish were taken in lower east coast catches, and that about 4,700 tons of lower east coast fish were caught on the west coast. Most of the west coast tags which were recovered on the lower east coast were from Area 23, and all of the lower east coast tags taken on the west coast were caught in Area 23 (Table II). It has also been observed in data of previous years that the interchange of lower east coast and west coast fish involved the more southerly west coast runs to a greater extent than the northern runs of the west coast population.

The tag-recovery data demonstrated movement of fish between the west coast and middle east coast in both directions, but the number of returns was too small to warrant detailed analysis. However, it is noteworthy that 1 of the 2 west coast tags recovered in middle east coast catches came from a fish tagged in Area 25 (Table II). Since all of the 8 west coast tags taken from lower east coast catches originated in Area 23, this suggests that in 1950–51 more herring might have migrated from the northerly west coast runs to the middle east coast than to the lower east coast. Although a differential emigration of Area 25 fish to the various Strait of Georgia runs has been suspected for several years, the 1950–51 data were the first to provide evidence of its existence from tag-recovery. Failure to obtain the pertinent data in previous years was probably due, in part, to the exceptionally small number of tags returned from the middle east coast fishery. The single middle east coast tag recovered in the west coast catch in 1950–51 was taken in Area 23.

The interchange of herring between the middle east coast and lower east coast was smaller in 1950–51 than in any season since the present tagging programme was initiated. The movement of lower east coast fish to the middle east coast was calculated to be 2.7 per cent ($^{8}/_{296}$), and the migration in the opposite direction amounted to 1.7 per cent ($^{3}/_{181}$). In the previous season, the former movement was 22 per cent and the latter was presumed, from the scanty data, to have been considerable (Stevenson and Lanigan, 1950). Although caution must again be used in dealing with few tag-returns, it appears reasonable to conclude that the smaller observed movement in 1950–51 was an indirect result of the location of the middle east coast fishery in that season. The fish were heavily exploited in Area 13 near the northern border of the sub-district, where the bulk of the

population enters the sub-district in the fall. As a consequence, there was apparently little movement of herring to the southern fishing area of the sub-district (Area 14), and no catches were made in the latter area. Since presumably most of the mixing between middle east coast herring and lower east coast herring occurs in the vicinity of Area 14, the failure of the middle east coast fish to move there in 1950–51 might have resulted in the small intermixture between the two populations.

Movement Within Populations

The probable number of 13-series (1949 taggings) and 14-series (1950 taggings) tags in the various west coast catches are summarized from Table II in the following tabulation, according to area of tagging (actual numbers of tags from which probable numbers were derived are given in parentheses):—

Area of Tagging	Area of Recovery 13-series					Area of Recovery 14-series				
	23	24	25	26	All Areas	23	24	25	26	All Areas
23	129 (12)	—	—	—	129 (12)	226 (34)	—	—	—	226 (34)
24	17 (1)	—	—	—	17 (1)	38 (7)	—	59 (1)	—	97 (8)
25	—	—	118 (2)	—	118 (2)	26 (3)	—	237 (4)	—	263 (7)
26	—	—	—	—	—	5 (1)	—	297 (5)	—	302 (6)
Totals	146 (13)	—	118 (2)	—	264 (15)	295 (45)	—	593 (10)	—	888 (55)

The small catches taken from Areas 24 and 26 yielded no tag-returns in 1950–51. It is also noteworthy that the Area 27 taggings carried out in 1950 (14-series) produced no returns in any west coast area catches in 1950–51, although a considerable number of Area 27 tags was recovered from outside the west coast sub-district (8 tags were returned from Area 7—Table II). This information might tend to corroborate past evidence that Area 27 herring are more or less distinct from other west coast runs (Stevenson, 1950, p. 46), but allowance should be made for the fact that catches in the more northerly west coast areas were small in 1950–51, exploitation was apparently low, and a relatively small proportion of the northern west coast catch was searched by tag-detectors. These factors indicate that limited opportunity was given for Area 27 tags to be recovered in the northern west coast areas.

All but one tag of the 13-series (1949 tagging) were recovered in the original tagging areas. Hence the current data suggest that there was considerably less wandering of the 13-series tags from the area of tagging than evidenced by the 14-series tags (1950 taggings). This is in direct contrast to results of previous years, which generally showed greater wandering of tagged fish which were longer at liberty. No adequate explanation can at present be given to account for this situation.

The average dispersal from tagging areas for the 14-series tags amounted to 48 per cent ($^{425}/_{888}$), the greatest dispersal for tags out less than one year ever calculated (Stevenson and Lanigan, 1950, p. 49). The exceptionally large probable number of Area 26 tags in the Area 25 catch mostly accounted for the apparently great dispersal. Considerable doubt is thrown on the accuracy of the estimated dispersal of Area 26 tags to Area 25 since only 2.4 per cent of Area 25 catch was searched for tags by tag-detectors.

As in most previous years, there was a tendency for herring to move south-easterly along the west coast rather than north-westerly. No Area 23 tags (14-series) were caught in the more northerly west coast areas in 1950–51, whereas it was calculated that 9.9 per cent ($^{26}/_{263}$) of the Area 25 tags (probable numbers) were taken in the Area 23 catch.

Data relating to movement of herring within the central sub-district, summarized from Table II, are tabulated as follows (actual numbers of tags on which probable numbers are based are shown in parentheses):—

Area of Tagging	Area of Recovery		
	6	7	Both Areas
6	51 (10)	17 (2)	68 (12)
7	.....	713 (79)	713 (79)
10	.....	78 (7)	78 (7)
Totals	51 (10)	808 (88)	859 (98)

The movement of herring from Area 6 to Area 7 (southerly movement) was calculated to be about 25 per cent ($^{17}/_{68}$), whereas no movement was shown in the reverse direction. Area 10 tags were recovered only in Area 7, suggesting a northerly movement. Thus, in 1950–51 it appears that considerable quantities of Area 6 and Area 10 herring were taken in the large Area 7 catch. To determine whether or not such movements of central herring consistently occur will require further study in future years.

Recovery of Tags by Plant Crews

In 1950–51 a total of 2,058 tags was recovered by plant crews from the magnets and plant-machinery of 15 reduction plants. A greater number of tags was recovered in only one previous year, 1948–49, when 2,940 tags were obtained. As mentioned previously in connection with tag-detector returns, the increased recovery of tags in 1950–51 over 1949–50 was primarily due to the extension of tagging and tag-recovery into Northern British Columbia waters. The number of tags submitted by each plant was as follows:—

Plant Code	Plant Name	Number of Tags	Plant Code	Plant Name	Number of Tags
A.	Imperial	231	K.	Alert Bay	86
B.	Namu	230	L.	Gulf of Georgia	86
C.	Port Albion	212	N.	Ecoole	60
D.	Kildonan	101	P.	Phoenix	53
E.	Ceepeecee	181	Q.	Colonial	161
F.	Nootka	204	R.	North Shore	64
H.	Butedale	244	S.	Shingle Bay	40
I.	Port Edward	105			

Plant tag-returns are of more limited value than tag-detector recoveries in studying herring movements, since doubt is sometimes attached to the place in which the fish bearing the tags were caught (Tester and Stevenson, 1948). However, the fact that the number of plant-returns is much greater than the number of detector-recoveries is often a distinct advantage in investigating the general movements of British Columbia herring. The distribution of the tags according to area of tagging and probable or certain area of recovery is given in Table III. Methods used to determine or assign the most probable areas of recovery were the same as in previous years (Tester and Stevenson, 1948). For 306 tags (15 per cent) the data were too inadequate to ascertain the general area of recovery.

To facilitate the analysis of the movement of fish between the various sub-districts, Table III is summarized as follows:—

Sub-district of Tagging	Sub-district of Recovery				
	Northern or Central	Upper, Middle, or Lower East Coast	West Coast	Indeterminate	Total
Northern	42			5	47
Central	675	55	6	123	859
Upper east coast	2	1	—	—	3
Middle east coast	8	89	2	9	108
Lower east coast	3	111	13	14	141
West coast	56	60	629	155	900
Totals	786	316	650	306	2,058

On the basis of plant-returns, the movement of west coast fish to other sub-districts amounted to 15.6 per cent ($^{116}/_{745}$), comprising a movement of 7.5 per cent ($^{56}/_{745}$) to the northern and central sub-districts and a migration of 8.1 per cent ($^{60}/_{745}$) to the east coast of Vancouver Island sub-districts. In the former migration, only 1 out of 40 tags to which specific sub-district of recovery could be assigned was considered to have come from northern catches (Table III). Thus, it appeared that the 7.5-per-cent movement was almost wholly to the central sub-district, giving an estimate of this movement slightly lower than that obtained from detector-returns (10.1 per cent). Likewise, most of the calculated movement of west coast fish to east coast sub-districts (8.1 per cent) was apparently to the lower east coast, since the numbers of tags considered to have been unquestionably derived from either the upper or middle east coast catches were relatively small. Thus the plant returns indicated a somewhat larger movement of west coast tags to the lower east coast than the 4.0 per cent migration calculated on the basis of detector-returns.

The emigration of lower east coast tags to sub-districts other than those of the east coast of Vancouver Island, as determined by plant-recoveries, amounted to 12.6 per cent ($^{16}/_{127}$), 2.4 per cent of the tags ($^{3}/_{127}$) being taken from northern or central catches and 10.2 per cent ($^{13}/_{127}$) coming from west coast catches. Movement to the north from the lower east coast was not shown by the sparse tag-detector returns, but movement to the west coast as derived from detector-recoveries (10.5 per cent) closely resembled that obtained from plant-recoveries, as given above. In addition, movement of lower east coast fish to the middle east coast sub-district was shown by plant-returns; although the data were not sufficiently precise to permit an estimate of the movement, the movement was apparently small and probably close to the calculation made from detector-returns (2.7 per cent).

The movement of middle east coast tags to sub-districts other than those of the east coast was calculated to be 10.1 per cent ($^{10}/_{99}$), with movement to the northern or central sub-districts amounting to 8.1 per cent ($^{8}/_{99}$) and migration to the west coast being 2.0 per cent ($^{2}/_{99}$). The extent of the movements of middle east coast herring, as given here, differs greatly from that calculated on the basis of detector-recoveries. The latter indicated no movement of middle east coast herring to northern waters, and suggested that about 9 per cent of the middle east coast fish moved to the west coast. In view of the small number of detector returns on which the detector calculations were based, it was considered that the extent of the movements as determined from plant-returns were the more reliable. The data pertaining to place of recovery were not sufficiently precise to permit estimation of the movement of middle east coast fish to the lower east coast, but it appeared that the plant-returns indicated a greater movement than the detector-returns (detector-recoveries indicated a movement of 1.7 per cent).

Plant-recovery of central tags suggested that central herring move much more extensively than would be interpreted from detector-results. The migration of central tags outside the central or northern sub-districts (calculated from plant-returns) was 8.3 per cent ($6\frac{1}{736}$), with 7.5 per cent ($55\frac{5}{736}$) going to east coast of Vancouver Island sub-districts and 0.8 per cent ($\frac{6}{736}$) moving to the west coast. In addition, by using only data on which place of recovery was fairly specific, it was estimated that about 8.4 per cent of the recovered central tags moved to the northern sub-district (Table III). Detector-returns indicated that no movement occurred to east coast sub-districts, 1.9-per-cent movement to the west coast, and no movement to the northern sub-district. It appears significant that the two estimates of migration to the west coast did not differ greatly. Assessment of the relative accuracy of the two methods in indicating the other movements will require further investigation.

Both plant-recoveries and detector-recoveries indicated a complete lack of movement of northern fish outside the northern and central sub-districts. However, plant-returns suggested that about 11.5 per cent of the northern tags moved to the central sub-district (Table III), whereas detector-tag returns, presumably because they were too few, failed to show any such migration. Although only limited reliability can be placed on the estimated 11.5-per-cent movement of northern fish to the central sub-district, and the previously mentioned 8.4-per-cent movement in the other direction, they suggest that in the interchange of northern and central herring, the central sub-district gained more fish than it lost in 1950–51. Obviously, the accuracy of this statement depends on the populations being of approximately equal size and the tags being well distributed throughout each population. The fact that the catches in the two sub-districts were similar (northern 50,650 tons, and central 51,314 tons) provides some evidence suggesting that the population abundance in 1950–51 did not differ greatly in these sub-districts.

Population Statistics from Tag-recoveries

On the assumption that the herring-fishery conforms reasonably well to one of the theoretical types of fishery (Type 1A) proposed by Ricker (1944), changes in exploitation rate and in initial abundance have been calculated for the west coast population in previous years. The value and the limitations of these statistics derived from tag-recovery and catch data have been discussed in preceding reports of this series. It should be pointed out that the methods used and the data available do not permit direct determination of the actual exploitation rate in any season, but rather they allow calculation of the ratio of the exploitation rates in two successive years. Making the assumption that tags are randomly distributed throughout the fishing stocks, the ratio of the exploitation rates in two consecutive fishing seasons should be approximately equal to the ratio of the probable percentages of first-year tags in the catches of the same two seasons. First-year tags are those tags which are derived from the tagging which took place in the spring immediately preceding the fishery—that is, tags which were out less than one year.

Probable percentage of first-year tags (13-series) in the 1949–50 catches was given in Table VII of the previous report (Stevenson and Lanigan, 1950), while the probable percentage of first-year tags (14-series) in the 1950–51 catches is presented in Table IV of this report. Since the probable percentage for each season is calculated on the basis of both detector-returns and magnet-returns, two possible estimates of the ratio of the exploitation rates are possible. However, considerable doubt was placed on the calculation derived from detector-recoveries in 1950–51, since only a very small proportion of the northerly west coast catch was searched for tags by detectors. In view of this, the ratio of the exploitation rates as derived from plant-returns was considered the more accurate. This ratio was calculated to be 0.71 (2.40/3.37).

As the exploitation rate decreased in 1950–51 over that in 1949–50, fishing effort also decreased. The fishing effort in 1950–51 was 0.67 that of the previous season.

These changes are in conformity with the theoretical relationship between fishing effort and exploitation rate in fisheries of this type (Ricker, 1940, Formula 19).

Previous calculations made on changes in rate of exploitation (Tester and Stevenson, 1948; Stevenson, 1950; Stevenson and Lanigan, 1950) suggest that the exploitation rate has decreased in the west coast populations for three successive years, in one of which (1949–50) the decrease was especially great, to 0.34 that of the preceding year. Evidently the rate of exploitation in 1949–50 and 1950–51 must have reached a low level absolutely. The small 1949–50 catch in Area 25 was apparently the result of low exploitation rather than reduced abundance (Stevenson and Lanigan, 1950), and further evidence suggests that the low Area 25 catch in 1950–51 resulted from the same cause (discussed later in this report). Since the exploitation rate has been small (in absolute terms) in the past two seasons, it might be reasoned that average population during each season should not differ greatly from the initial population, and hence catch per unit of effort should be approximately proportional to initial population (Ricker, 1940; pp. 50, 51). Comparison of catch per unit of effort in each year (47 tons per seine per day in 1949–50 and 48 tons per seine per day in 1950–51) indicates that the initial population was similar in each season. The initial population abundance in 1950–51 was calculated to be 0.94 that of the previous year (Ricker, 1940, Formula 20). Apparently the heavy recruitment of IV-year fish from the 1947 year-class maintained the population abundance in spite of the obvious weakness of the 1948 year-class (relative year-class strength is discussed in a later section of this report).

Tagging during the 1951 Spawning Season

Three seine-boats were again loaned by the fishing companies in the spring of 1951 to carry out the tagging programme. Two vessels operated in the lower and middle east coast sub-districts, one between mid-February and the first week of March, and the other from the last week in February to the second week in March. The third vessel operated alone in the west coast sub-district during the last week in February, and in early March it was joined by one of the boats from the east coast. The two boats then operated in the west coast sub-district for approximately three weeks in March. Subsequently, they were moved to central and northern waters, where tagging operations were carried on during the last week of March and the first week of April.

The large commercial-type purse-seine (Stevenson and Lanigan, 1950, p. 53), employed for the first time in the spring of 1949–50, again proved helpful in catching herring in deeper waters. Its use tended to increase efficiency in carrying out the tagging programme.

The following tabulation gives the number of fish tagged in the various areas in 1950 and 1951:—

Year	Sub-district and Area of Tagging														
	Northern		Central			Middle East Coast		Lower East Coast			West Coast				
	4	5	6	7	10	14	15	17A	17B	18	23	24	25	26	27
1950		2,548	6,578	4,404	1,012	2,019	4,046	6,090	3,082		8,025	2,011	10,081	4,510	2,029
1951	5,091		5,092	7,507	3,027		4,070	5,129	2,058	4,069	8,583	4,077	8,109	. . .	. . .

A total of 56,812 herring* was tagged in 1951, as compared with 56,435 in 1950. Taggings in the northern, central, and lower east coast sub-districts were increased,

* A list of all taggings made in 1951, including information on the date and place of each tagging and the identifying code letters of each lot of tags, will be supplied on request.

whereas fewer fish were tagged on the middle east coast and west coast. The decreased tagging on the west coast (20,769 fish tagged as compared to 26,656 in the previous year) resulted chiefly from failure to locate herring in Areas 26 and 27. In 1949, efforts to carry out taggings in these areas failed for the same reason.

As in past years, taggings were again made in Area 15 (middle east coast sub-district), but difficulties were again encountered in efforts to tag in Area 13. The decrease in the middle east coast tagging was attributable to misfortune in visiting Area 14 at times when spawning herring were not available.

Tagging in Area 18 was chiefly responsible for the increased number of fish tagged in the lower east coast sub-district in 1951.

Tagging of northern and central herring was resumed in 1950 after a lapse of five years. In 1951 more fish were tagged in both the northern and central sub-districts than in the previous year. The combined number of fish tagged in these two sub-districts in 1951 (20,717) represented the largest tagging programme ever carried out in Northern British Columbia waters.

SAMPLING OF THE CATCHES AND THE SPAWNING RUNS

Studies of year-class strength, rate of growth, sex ratio, and sexual development of the west coast herring population are being carried out through sampling the fishing and spawning runs. Age determination from scales gives the age composition of the catch, and thus provides information on relative year-class strength. A comparison of length and weight measurements from year to year shows growth differences, and data on sex ratio and maturity provide a link between the adult and spawn studies.

During the 1950–51 season a total of 52 samples* was taken in the west coast of Vancouver Island sub-district. The distribution of west coast sampling according to area is shown in the following tabulation (with comparable numbers for 1949–50 in parentheses):—

Area	Number of Samples	
	Fishery	Spawning Runs
23	38 (65)	4 (4)
24	2 (2)	2 (1)
25	2 (4)	4 (4)
26	(10)	(2)
27	( )	(1)

Age Composition

The average percentage age composition of the west coast fishing samples, weighted to numbers of fish caught in each individual area, is tabulated below for each season since quota restrictions were lifted in that sub-district:—

Year	In Year of Age								
	I	II	III	IV	V	VI	VII	VIII	IX–XI
1946–47	+	5.0	53.0	32.1	6.0	2.5	0.9	0.5	0.1
1947–48	+	2.4	58.2	27.8	8.5	2.1	0.5	0.3	0.1
1948–49	+	7.4	45.2	32.9	9.6	3.4	1.0	0.3	0.1
1949–50	+	4.4	68.8	20.5	5.3	0.8	0.2	0.1	—
1950–51	+	9.8	35.3	44.5	8.0	1.9	0.5	+	+

In 1950–51, fish of Age IV (1947 year-class) dominated the west coast catch for the first time since 1942–43. Moreover, the proportion of IV's in 1950–51 (44.5 per cent)

* A list of all fishing and spawning samples taken in 1950–51, including places and dates of sampling, numbers of fish of each age, numbers of fish of each sex, and data on maturity, will be supplied on request.

was larger than that found in the other two instances where IV-year fish dominated the catch. (In 1942–43 the IV-year fish formed 39.1 per cent of the catch and in 1931–32 they formed 36.9 per cent of the catch (Tester, 1948).)

This condition apparently resulted from (1) the great abundance of the 1947 year-class, which was strongly recruited as III's in 1949–50 and which entered the 1950–51 fishery stocks in large numbers, and (2) the relatively poor recruitment of the 1948 year-class as III's in 1950–51. The reduced recruitment of the 1948 year-class was predicted in 1950 from its contribution to the previous year's catch; indeed, as far back as 1948 there were indications of a relatively poor survival of the 1948 brood from reports on relative numbers of juvenile herring in Area 23 in 1947 and 1948 (Stevenson and Lanigan, 1950). Prospects for an abundant 1947 year-class were also noted in previous years. During the 1947–48 fishery, large numbers of I-year fish (1947 year-class) were present in inshore waters (Tester and Stevenson, 1948, p. 54). Although the significance of such an occurrence was not known, the possibility that the 1947 year-class would be of above-average strength was mentioned. Also this year-class entered the spawning runs of 1949 as II-year fish in tremendous numbers (Stevenson, 1950), and its strong representation in the fishing and spawning runs of 1949–50 indicated unusually great abundance (Stevenson and Lanigan, 1950).

Considering the number of fish of the various age-groups in the catches of recent years (tabulated below as millions of fish), the small number of III-year fish in the 1950–51 catch shows the poor recruitment of the 1948 year-class. The striking difference in the numbers of III- and IV-year fish in 1950–51 (Fig. 3A) compared with that of previous years emphasizes the strength of the 1947 year-class in relation to that of the 1948 year-class.

Fishing Season	Age									
	I	II	III	IV	V	VI	VII	VIII	IX+	Total
1946–47	0.13	27.02	288.72	174.70	32.53	13.65	4.88	2.49	0.47	544.79
1947–48	0.13	10.03	240.18	114.60	35.16	8.76	2.24	1.10	0.56	412.76
1948–49	0.30	36.83	224.02	163.00	47.52	16.84	5.05	1.66	0.45	495.67
1949–50	0.13	14.89	233.67	69.68	17.86	2.69	0.65	0.20	.....	339.77
1950–51*	0.08	22.27	80.17	100.93	18.05	4.36	1.04	0.04	0.04	226.98

* The number of fish of each age in the catches of each individual west coast area will be supplied on request.

It will be noted that the number of fish in the more abundant age-groups did not differ markedly from year to year, with the exception of III-year fish in 1950–51 (mentioned above) and IV-year fish in 1949–50. Considering the general uniformity of numbers of fish caught in most individual age-groups and the evidence indicating that population abundance has not varied greatly during the five-year period (discussed in a later section), the decrease in total numbers of fish caught in the past two seasons strongly suggests that a smaller proportion of the total population has been available to the fishery. Although the catch in 1947–48 was also less than in either 1946–47 or 1948–49, there is no suggestion in the data that it was caused by failure to locate as large a portion of the total population as in the other years. It was considered that the reduced 1947–48 catch was a result of a decrease in population abundance (Tester and Stevenson, 1948).

In view of the sharp decrease in the numbers of older fish in the past two seasons (shown in the previous tabulation), it might be reasoned that the large 1948–49 fishery exploited the population so heavily that the fishing stocks were greatly reduced. Although such a possibility exists and has been discussed in a previous report (Stevenson, 1950, p. 51), certain population statistics derived from other data have indicated not only that population abundance was maintained in the following year (1949–50) but that it had actually increased over that of the 1948–49 season (Stevenson and Lanigan, 1950, p. 52).

The 1947 year-class (IV-year fish) constituted a larger proportion of the Area 25 fishery than the Area 23 fishery (Table V and Fig. 3B), showing the tendency noted in past years for older fish to be better represented in runs of the more northerly west coast areas. On the other hand, the 1948 year-class (III's) formed a larger percentage of the Area 23 catch than of the Area 25 catch. In spite of this, it is considered that the weakness of the 1948 year-class was more instrumental in depressing the Area 23 catch than it was in reducing the size of the Area 25 fishery, which usually depends less on the recruitment of III-year fish than does the Area 23 fishery. The remarkably strong entry of the 1947 year-class in the latter area appeared to have more or less offset the effect of poor recruitment from the 1948 year-class, and the abundance of northern west coast stocks were maintained and probably increased. The major factor in the decreased Area 25 catch appeared to have been the delay in inshore migration of the runs and the subsequent intervention of the fishing closure date, which curtailed the potential catch.

Because of the large contribution of the 1947 year-class as III's in 1949–50 (68 per cent), a large influx of IV's was expected in the northerly west coast areas in 1950–51 and, along with it, a good fishery in Area 25 (Stevenson and Lanigan, 1950, p. 56). The 1950–51 catch was larger but not to the extent expected on the basis of age-composition studies, provided that the usual proportion of the population were available to the fishery. As will be discussed later, data from 1951 spawning surveys tend to substantiate the reasons given here for the small west coast catch in 1950–51.

Whereas the dominance of IV-year fish on the west coast prevailed in the two main fishing areas (Area 23 and Area 25), II-year fish dominated the samples from Area 24. The fishery in this area was small, however, and it is possible that the two schools from which samples were taken represented fish which had not yet been recruited to the main adult stocks. Nevertheless, the data show that even where the 1947 year-class failed to predominate, the III-year fish did not dominate the catch, suggesting that the weakness of the 1948 year-class was more or less universal on the west coast.

The age composition of the spawning samples was remarkably similar to that of the commercial catch. The marked increase in the number of II-year fish in the spawning samples, which was noted in the past three years, was absent this year, indicating little change in the constitution of the inshore herring stocks between the close of the fishery and the spawning-time.

The abundance of fish in 1951–52 will largely depend on the recruitment of the 1949 year-class as III's. Considering the entry of this year-class into the 1950–51 fishery as II's (9.8 per cent), it would seem that the 1949 year-class will be somewhat larger than that of 1948 and should produce "average" recruitment. The comparative failure of the 1948 year-class will probably result in a poor contribution of IV's to the 1951–52 fishery. Thus if the results of the age-composition studies were to be considered indicative, the Area 23 catch should be somewhat larger in 1951–52, while that in Area 25 will probably be smaller. However, if a larger portion of the stocks become available to the fishery in 1951–52 than in 1950–51, next season's catch might be larger in Area 25. The catch for the sub-district as a whole should probably be slightly larger than in 1950–51.

Sex Ratio and Stage of Development

The sex ratio (number of females divided by number of males) and sexual development in samples of herring from the 1950–51 commercial fishery and 1951 spawning runs are given in Table VI. It was noted that the sex ratios in 1950–51 took the opposite trend from that displayed during the previous four seasons. Since the west coast experiment was begun in 1946, males and females have tended to be equally abundant in the commercial catches, except in 1947–48, when females were more abundant. In the samples from the spawning runs, however, males have predominated. These differences

in sex ratio of fish in the fishing and spawning runs were considered to exist because (1) spawning fish were mostly younger than fish in the catch and (2) females tend to live longer than males (Stevenson and Lanigan, 1950).

With the increase in the average ages of both fishery and spawning samples over those for the previous year, an increase in the percentage of females would be expected if the above two principles held and if their effect was cumulative over the years. The proportion of females in the spawning samples did increase so that for the first time in the period under study females dominated the spawning samples. However, the percentage of females in the fishing samples decreased, in spite of the increase in average age, so that males were more numerous than females. If then, as previously maintained, the effects producing this relationship between sex ratio and average age are considered cumulative (that is, assuming that an increase in average age from one year to the next would increase the proportion of females in it regardless of changes in mean population age), it is apparent that the relationship does not hold for the 1950–51 data from fishing samples.

There is the possibility that a reversal in sex ratio, such as that noted in 1950–51, might have resulted from the radical increase in average age of the population, if the effect of the principles previously mentioned were not cumulative from year to year. However, it appears that more information relating to the problem is required before further analysis is warranted.

Immature fish formed a larger portion of the commercial catch than at any time over the previous four seasons, but the proportion involved (7.0 per cent) was still relatively small. For the first time in this period immature fish were taken in the spawning-run samples. This occurred in Area 25, where three immature fish were found in four samples. Two of these were well on the way to sexual maturity, but presumably development was checked by some factor such as disease, injury, or excessive parasitism. The third was presumably an immature female which had strayed into the spawning school. It is the first immature fish taken in a spawning sample in five years of intensive study.

About one-quarter of the fish in the spawning samples were spent. This proportion is comparable with that found for samples of the preceding four years, with the exception of 1948–49, when spent fish were more numerous (Stevenson, 1950).

Average Length and Weight

Annual variations in the average length and weight of fish of any particular age probably reflect the effect of environmental factors (feeding conditions, disease, etc.) which influence growth. The average weights of the various age-groups are also used, along with percentage age composition, to calculate the number of fish of each age in the commercial catches. The average lengths and weights of herring in the samples from the 1950–51 commercial catches are given in Table VII, and the average lengths of fish in samples from the 1951 spawning runs are given in Table VIII. Weights are not taken from the spawning-run samples, since differences in the percentage of spent fish in the sample would have a considerable effect on the average weight.

A comparison of average length and average weight for herring from each year of the investigation is given below:—

Year	In Year of Age				
	II	III	IV	V	VI
Length in Millimetres					
1946–47	*166*	187	203	213	222
1947–48	161	188	201	210	220
1948–49	159	188	201	213	222
1949–50	*164*	*190*	202	212	220
1950–51	159	188	203	213	220
Weight in Grams					
1946–47	*57*	86	113	133	151
1947–48	53	90	110	129	150
1948–49	50	87	111	138	*158*
1949–50	*56*	*94*	*117*	137	152
1950–51	50	88	114	135	148

Only minor changes in average length or weight have been evident in the west coast herring during the present investigation. Fish of all age-groups in the 1950–51 catch were lighter than those of the preceding year, suggesting that poorer feeding conditions existed in 1950 than in 1949. However, in 1949–50 the younger, newly recruited herring (II- and III-year fish) tended to be larger and heavier, and the IV-year fish tended to be heavier than in other years. Thus the factors influencing growth were probably slightly more favourable in the 1949 feeding season than in other recent years. The only other noteworthy differences were the longer and heavier II-year fish in 1946–47 (possibly due to better than average growth in the juvenile stage) and the heavy VI-year fish in 1948–49 (possibly due to sampling error). Consequently, it may be concluded that environmental conditions affecting the growth of the west coast herring have not changed appreciably during the period under study, although it seems probable that they were slightly more favourable in 1949 than in other years.

No difference in length and weight was evident in the herring sampled from the two major fishing areas (Area 23 and Area 25) during 1950–51, but herring from the fishing samples of Area 24 were considerably shorter and lighter than those from the other two areas (Tables VII and VIII). However, there were only two fishing samples and two spawning samples taken from Area 24, so they may not have been truly indicative of the size of the fish in that area. In the spawning samples, Area 23 fish tended to be larger than those of comparable age from Area 25. The results are similar to those of 1947–48 and 1948–49 but contrary to those of 1949–50. These relationships might indicate better feeding or other environmental conditions for Area 23 fish than for Area 25 fish, except in 1949–50, when the situation was reversed, possibly as a result of some change in oceanographic conditions.

A comparison by age-groups of fish from the catch and spawning samples shows that in all age-groups where over twenty fish were measured the fish from the spawning runs were longer than those from the commercial catch. Four alternatives are suggested: (1) Slight growth occurred in the interval between the fishery and spawning-time; (2) the samples were not representative of fish from the fishing and spawning runs; (3) the fishing and spawning runs formed two distinguishable groups or populations; and (4) that opposite extremes in the size range of the population were sampled in the fishing and the spawning samples. Evidence from previous sampling programmes and from scale studies indicates that the first alternative is unlikely. Also, since feeding does not resume until after spawning, no growth would be expected between the period of the fishery and the time of spawning. The second alternative is also improbable since the samples should be

as representative of the population in 1950–51 as in previous years, when the difference failed to show up. Fishing methods have remained relatively unchanged over the past five years, and, consequently, any selectivity introduced by this means would be more or less constant over the entire period. Sampling and age determinations were carried out by experienced technicians (and, to a large extent, by the same individuals) following standard procedures. Results of tagging and age-composition studies appear to preclude the third possibility.

An examination of the fishing samples shows a tendency for fish taken later to be longer than those captured at an earlier date, thus supporting the fourth alternative. However, none of the fishing samples had average lengths comparable to the spawning samples, so the process of increase in average length must have continued after the fishery stopped. This could be accounted for by the development of better feeding conditions toward the end of the summer feeding season. Thus those fish migrating earlier would be exposed to these more favourable conditions for a proportionately much shorter period than those migrating later. The more or less continuous movement involved in the inshore migration should produce a more or less gradual gradation in size. This latter condition was found in the 1950–51 samples, and, consequently, the hypothesis of a gradation in size within the population during 1950–51 seems the most likely explanation.

EXTENT AND INTENSITY OF SPAWNING

Studies of the extent and intensity of herring spawnings are carried out to assess the relative abundance of spawning stock from year to year and to provide basic data on the year-class produced by that spawning. Since 1947, members of the herring-investigation staff have surveyed the major west coast spawning-grounds, and their reports, along with the reports of independent surveys by fisheries officers, are used to compare the amount of spawn deposited from year to year. Methods employed in the 1951 survey were similar to those used in previous years (Tester and Stevenson, 1948).

The 1951 west coast spawning followed a similar pattern to previous years (Stevenson and Lanigan, 1950; Stevenson, 1950; Tester and Stevenson, 1947, 1949). The main spawning-grounds* were:—

Area 23: Toquart Bay and Village, Macoah Passage, and Useless Inlet.
Area 24: Cypress Bay, Mosquito Harbour, Quait Bay, and Whitepine Cove.
Area 25: Nuchatlitz Village, Kendrick Inlet, Double Island, and Spanish Pilot Group.
Area 26: Union Island.
Area 27: Leeson Harbour, Hazard Point, and Klaskino Inlet.

The most striking features of the 1951 spawnings were: (1) The immense spawning (21.6 miles) in the Nuchatlitz Village vicinity in Area 25, which accounted for nearly half of the total west coast deposition and was the major factor in the record spawning which occurred in Area 25; (2) the lack of spawning around the Stopper Islands and in Sunshine Bay in Area 23; (3) the small spawnings in Mayne Bay and in the Banfield Inlet-Grappler Inlet vicinity (Area 23); (4) the spawning on Forbes Island (Area 23) noted this year for the first time; (5) the general increase in the number of spawning-grounds in Area 24; (6) the almost complete lack of spawning in the Port Eliza-Queen Cove locality (Area 25) for the second successive year; and (7) the lack of spawning in Ououkinsh Inlet (Area 26).

The extent of spawning on the west coast of Vancouver Island was greater than that at any time during the last five years. The increase in extent over last year was only slightly larger than the increase in the Nuchatlitz spawning alone. Due to this large

* A list of the individual spawning localities with dates, intensity, and extent of spawn deposition will be supplied on request.

spawning, the extent of spawn deposited in Area 25 amounted to over half that deposited on the west coast. The Area 24 spawning extent was also a record for the past five years, more than doubling the previous year's total for the area. This was mainly a result of unusually large spawnings in Cypress Bay and Mosquito Harbour. The Area 23 spawning of 1951 was considerably reduced from that of 1950, and was the lowest recorded in the five years of the investigation. The decrease was apparently due largely to reduced spawning in Macoah Passage, in Mayne Bay, and in Banfield Inlet vicinity, as well as the complete failure of several other spawnings. As in Area 23, the extent of spawning in Area 26 reached a record low. All spawnings in this area were either markedly reduced or failed completely. The Area 27 spawnings did not differ appreciably in either location or extent from those of the previous year.

The extent of spawn (in statutory miles) is tabulated below by area for 1950 and 1951:—

Area	Extent in Miles 1950	1951
23	13.4	8.8
24	4.2	11.4
25	18.2	28.3
26	3.2	1.5
27	4.5	4.9
All areas	43.5	54.9

The average spawning intensity for 1951 on the west coast was virtually unchanged from the 1950 level. Some variation within the individual areas occurred, as may be seen in the following tabulation. Average intensities of the spawn deposition were calculated by weighting the various intensities of the individual spawnings—very light, light, medium, heavy, and very heavy—in the ratio of 1, 2, 3, 4, and 5, respectively, and by correcting for extent of the individual depositions.

Area	Average Spawning Intensity 1950	1951
23	2.4	2.9
24	2.8	1.3
25	3.2	3.4
26	3.3	3.4
27	3.0	3.1
All areas	2.9	2.9

Since the intensity of spawning did not change appreciably from 1950 to 1951, the increase noted in the extent of spawn deposition apparently represented an increase in the actual amount of spawn deposited. It would thus seem that a relatively large number of fish escaped the fishery and that the low west coast catch in 1951 probably reflected, in part, a failure of the fishing fleet to locate fish rather than a decrease in population abundance. This was especially true in Area 25, where the spawning extent was much larger and the intensity the same as in the previous year. The drop in extent of spawn in Area 23 in 1951 was partly balanced by an increase in intensity. The extent of spawn in Area 24 was more than double that of 1950, but its intensity was less than half that of the previous year. Intensities in Area 26 and 27 remained similar to those of the previous year.

Thus considering both intensity and extent of spawning, the slight decrease in the amount of spawn deposited in Areas 23 and 26 was more than compensated for by the record spawning in Area 25. The amount of spawn deposition in the other areas did not vary appreciably from that deposited in 1950. It would therefore seem that removal of the quota on the west coast herring-catch in 1946–47 has not been followed by reduction

in the spawning stocks below the level necessary to maintain the population (Stevenson and Lanigan, 1950). On the contrary, it appears that lack of availability of herring to the fishing fleet in Area 25 has become a significant factor in reducing catch and increasing spawn deposition to a level which is possibly unnecessarily large for maintenance of the stocks.

DISCUSSION

In the foregoing sections of the report, various changes which occurred in the 1950–51 west coast of Vancouver Island population have been analysed in a manner similar to that employed in previous years of the study. It was pointed out that the 1950–51 catch, unrestricted by quota, was the smallest of the five-year period, but that the spawning stock had reached a record high. Evidence from tag-recovery indicated that initial population abundance in 1950–51 was about the same as in the previous year. The maintenance of population abundance was attributed to the remarkable productivity of the 1947 year-class, which as IV-year fish overshadowed the poorly recruited 1948 year-class. The increase in population abundance in 1949–50 over 1948–49 resulted from the exceptionally high recruitment of the 1947 year-class as III-year fish (Stevenson and Lanigan, 1950).

The 1947 year-class was also heavily recruited to the lower east coast stocks in 1949–50, but the year-class was apparently somewhat less productive than on the west coast. The 1946 year-class (IV-year fish) made only a small contribution to the lower east coast stocks in that season, and, as a result, population abundance on the lower east coast declined in 1949–50. The 1948 year-class entered the 1950–51 fishing population strongly and population abundance increased; catch per unit of effort was greater than in the previous season; and spawn deposition was more intensive.

In reviewing these results along with those of the previous years, it can be concluded that population abundance has remained at a generally high level in both populations throughout the period. However, certain year-classes have differed greatly in the extent of their recruitment to these two populations. Although the populations under investigation are more closely related with regard to geographical location and extent of intermixture than any other British Columbia populations of comparable size, some year-classes have been highly productive in one and relatively poor in the other. The main reason for the continued high abundance in each has arisen from the fact that average year-class production during the period has been about the same in each sub-district.

These conclusions bear directly upon the practical object of determining the utility of the quota system of management. If population abundance can be maintained without catch quotas, as on the west coast, then it appears that the fixed quota on the lower east coast population has not aided in stabilizing population abundance. Indeed, the striking increase and subsequent decrease noted in the lower east coast population in previous years (Stevenson and Lanigan, 1950, pp. 59, 60) might possibly indicate that the quota has unduly restricted catch. In this regard the extent of recruitment from the large 1949 lower east coast spawning in the coming season will be of special significance. Present evidence indicates that 1949 year-class will be less abundant than the 1948 year-class, which was derived from a smaller spawning. If this prediction is accurate, the large 1949 escapement permitted through application of a fixed quota will therefore suggest wastage of the stocks. Moreover, past data have failed to show that the population under quota regulations tended to receive greater year-class recruitment (on the average), since, as indicated previously, average year-class strength during the past five years has been similar in both populations. Thus, in so far as population abundance is concerned, there has been no evidence of benefit from restricting catch by quota, at least while average year-class strength is high.

Results of the present study indicate that catch can be restricted even when catch quotas are not applied. There is evidence that fishing effort was sometimes limited by the industry in one population for the purpose of concentrating effort on other stocks. Also availability of herring to the fishing fleet is at times unusually low in certain populations. For both reasons, catch has apparently been limited on the west coast of Vancouver Island, but such limitations have not been noted on the lower east coast.

An incident of transference of the fishing fleet occurred in Area 23 in December, 1950. At the time, moderately good catches were being made, then practically the entire fleet was sent to the northern sub-district to take part in the exceptionally heavy fishery which had developed. In this case the potential catch in Area 23 was undoubtedly reduced, but generally this type of catch curtailment, arising wholly from attempts of the fishing industry to deploy the fleet with maximum efficiency, is a minor factor influencing catch.

A much more significant factor in determining eventual catch is variation in the availability of the herring runs to the fishing fleet. In 1949–50 and 1950–51 there was evidence that herring of the more northerly section of the west coast (particularly herring which spawn in Area 25) were subjected to relatively light exploitation. It appeared that in 1949–50 the main inshore migration into Area 25 did not occur until after the fishing closure date of February 5th. In the 1950–51 season the Area 25 runs were heavily fished as they began moving inshore in late January, but the closure date abruptly curtailed the potential catch. There has never been any obvious indication that the lower east coast population has similarly suffered from lack of availability or lateness of inshore migration.

Although natural limitations on catch differ in type from quota restrictions, their effect is essentially the same. In 1950–51, reduced availability in a portion of the west coast stocks led to greatly increased spawn deposition, and hence to possible wastage of fish—a situation similar to that which occurred on the lower east coast in 1948–49, apparently as a result of the application of quota regulations. Possibly other methods of fishing to increase exploitation might be practical when and where natural limitations to fishing prevail. Postponement of the closure date would not seem advisable, because of the danger of extremely heavy exploitation when the herring become densely schooled prior to spawning. At any rate, it is obvious that curtailment of the west coast catch has considerably complicated the experimental aspect of the study. Should such conditions continue in future years, a longer period of investigation might be required to draw definite conclusions on the most effective type of herring management.

Unfortunately, little is known about the factors that influence availability of herring beyond the possibility that water temperature might be involved (Stevenson and Lanigan, 1950, p. 44). Further research along this line appears to be highly desirable.

As pointed out in the previous report, there is need to continue the present investigation during a period of generally low recruitment to the populations. Information gained from study during relatively high abundance will not necessarily apply when population abundance is low. In particular, it appears desirable to obtain knowledge on the significance of natural limitations to catch under such conditions of abundance.

SUMMARY

This is the fifth in a series of annual reports on the results of an intensive study on a herring population (that of the west coast of Vancouver Island) which is not subjected to quota restrictions on catch. Comparative data on another major herring population on which fixed quota regulations are applied (the lower east coast of Vancouver Island population) are also discussed, the object being to determine ultimately whether or not catch quotas are effective in stabilizing herring populations. In striving for a solution to

this practical problem, it is anticipated that information relating to various fundamental fisheries problems will be obtained.

The west coast catch in 1950–51 (25,200 tons) was the smallest of the five-year period. However, catch per unit of effort showed no decrease from that of the previous year, suggesting that population abundance did not differ greatly in the two years. The decrease in fishing effort (528 seine-days as compared to 790 in the previous year) and the resultant small catch were considered to have been caused, at least in part, by the late inshore movement of the Area 25 runs, and, to a lesser degree, by removal of fishing vessels from Area 23 to more productive fishing-grounds in the northern sub-district.

On the basis of tag-returns and catch data, it was calculated that the ratio of initial population abundance in 1950–51 and the previous year was 0.94, giving further evidence that population abundance on the west coast was similar in both seasons. Calculation of the ratio of the exploitation rates in the two years from tagging data (0.71) suggested that a smaller proportion of the total population was caught in 1950–51 than in the previous year.

The 1947 year-class (IV-year fish) dominated the west coast catch as a whole, as well as the commercial runs of each of the two major fishing areas (Areas 23 and 25), and the 1948 year-class (III-year fish) was poorly represented in all west coast catches. Apparently the unusual abundance of the 1947 year-class maintained population abundance in spite of the poor recruitment of the 1948 year-class. The remarkable productivity of the 1947 year-class was predicted by various data of previous years: (1) Its strong entry into the fishing and spawning runs in 1949–50 as III-year fish; (2) the tremendous influx of the year-class in the spawning runs of 1949 as II-year fish; (3) its unusual abundance as I-year fish on the fishing-grounds in the 1947–48 season; and (4) reports received in the summers of 1947 and 1948 indicating that juvenile herring were more abundant in 1947 than in 1948.

The 1947 year-class was relatively more abundant in Area 25 than in Area 23 in 1950–51. This is in conformity with a tendency, noted in previous years, for recruitment of a strong year-class to be greater in Area 25 than in Area 23. As a result of this tendency, it is considered that the herring abundance in more northerly areas of the west coast was probably greater than in more southerly areas. Thus it appears that if the Area 25 herring had come inshore earlier in the fishing season, the catch would have been much greater than it was. Data obtained from spawning surveys (assuming spawn deposition to be proportional to escapement) tended to confirm this view. The Area 25 spawn deposition reached a record extent, whereas in Area 23, where herring were less abundant and where the runs were more thoroughly exploited, spawning was greatly reduced.

Because of the extremely large spawning in Area 25, spawn deposition on the west coast as a whole in 1950 increased over that of the previous year, and constituted the largest spawning of the five-year period.

Although the 1947 year-class was abundant in the lower east coast population, it was apparently less so than on the west coast. However, the 1948 year-class was much more productive than on the west coast. Thus population abundance on the lower east coast increased in 1950–51 over that of the previous year. Evidence for the increase was shown by an increase in catch per unit of effort and a more extensive spawn deposition.

Results of five years of study indicate that population abundance in both populations has remained at a generally high level throughout the period. Although certain year-classes have differed greatly in the extent of their recruitment to these two populations, the average year-class recruitment has been about the same in each sub-district. Thus, since population abundance can apparently be maintained without catch quotas, as on the west coast, it appears that there has been no benefit derived from restricting catch by quota on the lower east coast. Indeed, data obtained during one season might be con-

sidered to indicate that the quota has, on at least one occasion, unduly restricted the lower east coast catch. This interpretation is based on the assumption that the two populations are in most respects comparable. However, the possibility exists that the lower east coast population may react differently from the west coast population if the quota were removed. Hence further study is essential before the above indications can be considered conclusive.

The strong evidence indicating that in the past two years availability of herring to the fishing fleet has been unusually low in Area 25 suggests that natural limitations of this type to catch have essentially the same effect as if catch quotas were applied. To a certain extent, these natural limitations complicate the experimental basis of the present study. It appears desirable to have information on their effect over a period of generally low abundance.

In addition to the results discussed above, the present report includes an analysis of tag-recovery data from the standpoint of herring movements, an interpretation of the 1950–51 sex ratio data, and a discussion on growth data obtained in 1950–51 and in previous seasons.

Although herring movements between all major herring populations and within certain populations are discussed, emphasis is placed on the data dealing with movements which concern the west coast and lower east coast populations. As in past years, tag-returns showed that a considerable portion of west coast fish moved to other sub-districts (both tag-detector returns and plant-recoveries suggested about 15 per cent). Plant-returns indicated that 8 per cent of the west coast fish moved to the east coast of Vancouver Island sub-districts (mainly the lower east coast), and over 7 per cent moved to the central or northern sub-districts (mainly the central sub-district). Detector-returns indicated that 10 per cent moved to the central sub-district, 1 per cent to the middle east coast, and 4 per cent to the lower east coast. The percentage of west coast tags which were taken from the central catches was considerable, and this implied movement will be further investigated in the second season of intensive tag-recovery in Northern British Columbia waters. The percentage movement of west coast fish to the lower east coast in 1950–51 was smaller than in the previous season (11 per cent) but similar to that in earlier years.

Lower east coast fish moved mainly to the west coast, and the extent of movement was similar in each of the past two years (about 10 per cent). Plant-returns showed a movement of lower east coast tags to the central and northern sub-districts amounting to more than 2 per cent, but detector-returns failed to show such a migration.

Central tags were recovered on both the east coast and the west coast of Vancouver Island. The former movement (about 7 per cent) was shown only by plant-returns, but both methods of recovery indicated that central fish were taken on the west coast (1 per cent for plant-returns and 2 per cent for detector-returns).

Further analysis of the data suggested that a greater quantity of lower east coast fish was taken in west coast catches than vice versa (4,700 tons and 900 tons respectively). On the other hand, approximately the same amount of central herring were taken in west coast catches as west coast herring taken in central catches (1,000 tons and 1,400 tons respectively).

Considering the movement of herring within the west coast sub-district, it was found that, as in previous years, there was a distinct tendency for herring to move south-easterly along the west coast rather than northwesterly. However, the small catch in Area 25 and the small amount of the Area 25 catch searched for tags by tag-detectors might have partly accounted for the lack of Area 23 tags recovered in the more northerly west coast areas. The average dispersal of tags from tagging areas amounted to 48 per cent, the greatest dispersal ever noted.

ACKNOWLEDGMENTS

During the 1950–51 season the herring investigation again received the wholehearted support of numerous organizations and individuals. To them we express our sincere appreciation.

The assistance which the fishing companies provided in various ways is gratefully acknowledged. British Columbia Packers, Limited, again permitted tag-detector installations in two of their reduction plants, located at Steveston and Kildonan, and the Canadian Fishing Company, Limited, provided similar facilities for the operation of a tag-detector at their Steveston plant. The pleasant relations which existed between the managers of these plants and personnel of the investigation were deeply appreciated.

In addition, the companies supplied the vessels which were used to carry out various parts of the herring-research programme. Nelson Brothers Fisheries, Limited, loaned the *Percy W.* for general contact work during the period of the fishery and for scouting herring and the *Ribac* for tagging in the spring. British Columbia Packers, Limited, made available the *Dominion No. 1* for the tagging programme, and the Canadian Fishing Company, Limited, loaned the *Pacific Sunset* for tagging and for spawn studies. The help and personal interest shown by the captains and crews of these vessels in the various research programmes were sincerely appreciated.

The investigation was assisted in many ways by the employees of the reduction plants. Plant crews again searched magnets and plant machinery for tags, and submitted them with the required information concerning place and date of recovery. Plant personnel assisted in collecting samples from herring-catches at certain plants. Prior to January 1st, 1951 (before the Marketing and Economics Service of the Federal Department of Fisheries undertook coastwise compilation of catch statistics) the plant bookkeepers directly provided records of individual plant landings, which permitted estimates of catch by area.

The captains of herring seine-boats submitted catch records, which allowed computation of catch per unit of effort.

In addition to providing specific catch statistics for all fisheries after January 1st, 1951, and over-all catch totals throughout the season, the Federal Department of Fisheries, through the efforts of their fisheries officers, again undertook surveys of the extent and intensity of herring-spawn in all coastal areas. For these services, and for numerous other courtesies shown by the Chief Supervisor, A. J. Whitmore, and by the Regional Supervisors, J. F. Tait and G. S. Reade, the investigation is deeply indebted.

Sincere appreciation is extended to the staff members of the investigation for the conscientious efforts they have put forth in the interests of the research and for the cooperative spirit they have consistently shown. Mrs. Anne Lazareff Herlinveaux, junior scientist, and R. S. Isaacson, senior laboratory technician, made age determinations and supervised the compilation of age and growth data. Mr. Isaacson also compiled and analysed the catch statistics derived from various sources. A. G. Paul, senior field technician, undertook major responsibilities in the tagging and tag-recovery programmes and in the maintenance of non-electrical equipment. J. H. Larkman, field technician, serviced and overhauled tag-detectors and other electrical equipment, carried out various other duties in connection with tag-recovery, and undertook responsibility in tagging operations. Other members of the technical staff, B. Wildman, K. A. Herlinveaux, J. A. Saker, and D. McDermott, assisted at one time or another in the various phases of the field work and aided in the preliminary analysis of the data. Miss Alice Nyquist ably carried out the stenographic and clerical work of the investigation.

K. J. Jackson and D. N. Outram, junior scientists, devoted much of their time to studies of survival of herring-spawn. In addition, they undertook responsibility in connection with various field programmes.

During most of the past year, while the senior author was on educational leave, the plans of the research were carried out jointly by the junior authors. A. S. Hourston, assistant scientist, supervised the studies relating to early life-history and took over various administrative duties; J. A. Lanigan, junior scientist, had charge of the field studies dealing with the adult herring. In the present report, Mr. Lanigan was responsible for the preliminary analysis of most of the tagging and tag-recovery data and for the final analysis of some of them, and Mr. Hourston was responsible for the analysis of the sampling and spawning data. For other sections of the report, and for the general interpretation of the results of the 1950–51 studies which are reported herein, the senior author assumes chief responsibility.

For a number of years this series of annual reports has been published by the Provincial Fisheries Department of British Columbia. To G. J. Alexander, Deputy Minister of Fisheries, we extend deep appreciation for his continued interest in the herring studies.

Lastly, it is a sincere pleasure to acknowledge the stimulation, encouragement, and valuable advice which have been offered by Dr. J. L. Hart, Director of the Pacific Biological Station, throughout the past year.

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* Reprints were published in 1951.
† Reprints were published in 1949.

Table I.—Catch (Tons), Fishing Effort (Total Number of Active Fishing-days Expended by All Seine-boats), and Catch per Unit of Effort (Average Catch per Seine per Day's Active Fishing) for West Coast Areas during the 1950–51 Fishing Season.

Area	Estimated Catch	Fishing Effort*	Catch per Unit of Effort
23	17,800	406	43.8
24	400	24	17.0
25	6,750	85	79.3
26	250	9	28.8
27		4	.....
Totals	25,200	528	47.7

* The total number of active fishing-days is calculated to the nearest whole number from catch per unit of effort based on incomplete data and from estimated catch.

Table II.—Probable Number of Tags in the Catches during the 1950–51 Season, Based on Detector Returns, with Actual Number of Recoveries Shown in Parentheses

Tagging Area	Tagging Code and Year	Area of Recovery										Total
		5	6	7	12	13	17A	17B	18	23	25B	
5	14CC (1950)	77 (2)										77 (2)
6	14AA (1950)		15 (3)									15 (3)
	14BB (1950)		36 (7)	17 (2)								53 (9)
7	14HH (1950)			260 (27)								260 (27)
	14KK (1950)			453 (52)						17 (1)		470 (53)
10	14EE (1950)			78 (7)								78 (7)
12	9I (1945)				13 (1)							13 (1)
	10H (1946)				10 (1)							10 (1)
14	14A (1950)					48 (6)			3 (1)	17 (1)		68 (8)
15	13A (1949)					4 (1)						4 (1)
	14B (1950)					52 (7)						52 (7)
	14C (1950)					57 (8)						57 (8)
17A	14E (1950)					4 (1)	4 (1)	24 (1)	20 (3)			52 (6)
	14F (1950)						4 (1)	13 (2)				17 (3)
17B	14G (1950)						13 (1)	13 (2)		14 (2)		40 (5)
	14H (1950)						4 (1)	118 (5)	7 (2)			129 (8)
18	13E (1949)					4 (1)	13 (1)					17 (2)
	13F (1949)							24 (1)				24 (1)
23	11F (1947)									17 (1)		17 (1)
	11H (1947)									5 (1)		5 (1)
	12G (1948)						13 (1)			14 (3)		27 (4)
	12H (1948)									15 (1)		15 (1)
	12I (1948)									5 (1)		5 (1)
	12K (1948)									6 (1)		6 (1)
	13G (1949)									5 (1)		5 (1)
	13H (1949)					4 (1)				54 (4)		58 (5)
	13I (1949)							24 (1)		70 (7)		94 (8)
	14I (1950)								3 (1)	73 (12)		76 (13)
	14K (1950)									42 (6)		42 (6)
	14L (1950)						4 (1)	6 (1)		76 (12)		86 (14)
	14M (1950)						4 (1)		3 (1)	35 (4)		42 (6)
24	10L (1946)									17 (1)		17 (1)
	12L (1948)									5 (1)		5 (1)
	12M (1948)									6 (1)		6 (1)
	13L (1949)									17 (1)		17 (1)
	14N (1950)									38 (7)	59 (1)	97 (8)
25A	13M (1949)			7 (1)							59 (1)	66 (2)
	13P (1949)										59 (1)	59 (1)
	13Q (1949)					16 (1)			3 (1)			19 (2)
	14Q (1950)									12 (2)	59 (1)	71 (3)
	14R (1950)										59 (1)	59 (1)
	14S (1950)									5 (1)		5 (1)
25B	14T (1950)									9 (2)	119 (2)	128 (4)
26	12T (1948)			9 (1)								9 (1)
	12U (1948)										59 (1)	59 (1)
	14V (1950)			46 (3)						5 (1)	178 (3)	229 (7)
	14W (1950)										108 (2)	108 (2)
27	12X (1948)			9 (1)								9 (1)
	14X (1950)			81 (7)								81 (7)
	Totals	77 (2)	51 (10)	960 (101)	23 (2)	189 (26)	59 (8)	222 (13)	39 (9)	579 (75)	759 (13)	2,958 (259)

Table III.—Number of Tags Recovered by Plant Crews, According to Area of Tagging and Probable Sub-district of Recovery, for the 1950–51 Fishing Season

Tagging Area	Tagging Code	Probable Sub-district of Recovery										Total
		Northern	Central	Northern and Central	Upper East Coast	Middle East Coast	Lower East Coast	Upper—Lower	Middle—Lower	West Coast	?	
5	9P		2	1								3
	9Q	2										2
	14CC	21	1	15							5	42
6	9N		1	1								2
	9O								1			1
	14AA	14	6	16			2				7	45
	14BB	17	15	33				1			12	78
	14DD	1	8	6							4	19
7	9L		1	1								2
	9M		1	1								2
	14HH	1	130	70	7		3	7	3		38	259
	14KK	2	225	92	3	2	6	12	2	5	53	402
10	9K	2	3	1		1					1	8
	14EE		16	11		1	1	1	2	1	8	41
12	9H			1				1				2
	10H			1								1
14	12A						2					2
	13B									2		2
	14A	1					4	4	7		1	17
15	8D					1						1
	13A					1	3	1			1	6
	14B		2	1		4	2	4	11		3	27
	14C		1	3		8	5	9	22		4	52
16	10F								1			1
17A	11D						1				1	2
	13C									1		1
	14D			1			2		4		1	8
	14E						9	1	3	1		14
	14F						11	1	6		2	20
17B	14G					1	20		2	4	5	32
	14H		1				22		11	6	4	44
18	13E			1			6		1			8
	13F						2	1	7	1	1	12
23	11F										1	1
	11H									6		6
	11I										1	1
	11K								1		1	2
	11M									3		3
	11N						1			1		2
	12G									10	2	12
	12H						1		1	2	1	5
	12I			1						2		3
	12J									3	1	4
	12K									1	1	2
	13G									16	8	24
	13H		1	2		1	5	1	1	18	9	38
	13I						6		4	26	11	47
	14I						3	1	2	56	11	73
	14K						1			17	3	21
	14L			1	1		6	1	1	59	12	81
	14M							1		30	3	34
24	11P									1	2	3
	12L		1							3		4
	12M									4	1	5
	13K						1	1		5	3	10
	13L									8	2	10
	14N						1			32	5	38

Table III.—Number of Tags Recovered by Plant Crews, According to Area of Tagging and Probable Sub-district of Recovery, for the 1950–51 Fishing Season—Continued

Tagging Area	Tagging Code	Probable Sub-district of Recovery										Total
		Northern	Central	Northern and Central	Upper East Coast	Middle East Coast	Lower East Coast	Upper—Lower	Middle—Lower	West Coast	?	
25A	11U								1			1
	12N									1	1	2
	12P									1		1
	12Q								1	2	2	5
	13M			1	1		1			13	3	19
	13N				1			1		2		4
	13P					1				7	1	9
	13Q									5	1	6
	14P									1	1	2
	14Q									28	3	31
	14R		1							5	5	11
	14S		1				2			7	4	14
25B	11W									1	1	2
	11X									1		1
	12R									1		1
	12S									4		4
	13R									6	2	8
	13S		2						1	23	7	33
	14T						1			39	9	49
	14U									17	3	20
26	10R									1		1
	12T									3		3
	12U		1							3	1	5
	14B		5			1				66	12	84
	14W		2	1						71	8	82
27	12W									1		1
	12X		2	2					1	4	2	11
	14X	1	23	8			1	4		13	11	61
	Totals	62	452	272	13	22	131	53	97	650	306	2,058

Table IV.—Number of West Coast Tags Used, and Probable Number and Percentage in the 1950–51 West Coast Catch, According to Calculations Based on Recoveries by Both Detectors and Plant Crews.

Tagging Area	Tagging Code	Number Used	Probable Number in Catches		Probable Percentage in Catches	
			Detector Returns	Plant Returns	Detector Returns	Plant Returns
	Tagged in 1948; Present in 1950–51 Catches					
23	12G	1,511	14	19	0.93	1.26
23	12H	1,053	15	4	1.42	0.38
23	12I	2,082	5	4	0.24	0.19
23	12J	2,025	.....	5	.....	0.25
23	12K	2,548	6	4	0.24	0.16
24	12L	3,063	5	5	0.16	0.16
24	12M	2,516	6	7	0.24	0.28
25	12N	1,986	.....	2	.....	0.10
25	12P	2,019	.....	1	.....	0.05
25	12Q	1,503	.....	2	.....	0.13
25	12R	1,985	.....	2	.....	0.10
25	12S	1,524	.....	5	.....	0.33
26	12T	2,043	.....	4	.....	0.20
26	12U	1,515	59	5	3.89	0.33
27	12W	1,381	.....	1	.....	0.07
27	12X	3,193	.....	5	.....	0.16
	Totals	31,947	110	75	0.34	0.23
	Tagged in 1949; Present in 1950–51 Catches					
23	13G	1,517	5	34	0.33	2.24
23	13H	3,062	54	36	1.76	1.18
23	13I	3,071	70	52	2.28	1.69
24	13K	1,004	.....	8	.....	0.80
24	13L	2,032	17	12	0.84	0.59
25	13M	2,024	59	17	2.92	0.84
25	13N	2,022	.....	2	.....	0.10
25	13P	2,039	59	11	2.89	0.54
25	13Q	1,025	.....	7	.....	0.68
25	13R	2,028	.....	7	.....	0.35
25	13S	2,032	.....	30	.....	1.48
	Totals	21,856	264	216	1.21	0.99
	Tagged in 1950; Present in 1950–51 Catches					
23	14I	2,016	73	98	3.62	4.86
23	14K	2,003	42	33	2.10	1.65
23	14L	1,994	76	110	3.81	5.52
23	14M	2,012	35	47	1.74	2.34
24	14N	2,011	97	55	4.82	2.73
25	14P	505	.....	2	.....	0.40
25	14Q	1,511	71	41	4.70	2.71
25	14R	2,015	59	7	2.93	0.35
25	14S	1,017	5	12	4.92	1.18
25	14T	2,543	128	65	5.03	2.56
25	14U	2,490	.....	22	.....	0.88
26	14V	2,019	182	97	9.01	4.80
26	14W	2,491	108	105	4.34	4.22
27	14X	2,029	.....	19	.....	0.94
	Totals	29,656	876	713	2.95	2.40

Table V.—Average Percentage Age Composition of Samples from Commercial Catches and from Spawning Runs during the 1950–51 Season

COMMERCIAL CATCHES

Area	Number of Samples	In Year of Age								
		I	II	III	IV	V	VI	VII	VIII	IX
23	38	0.03	9.45	39.49	42.57	6.74	1.39	0.27	0.03	0.03
24	2	0.51	85.98	9.84	3.67	—	—	—	—	—
25	2	—	1.54	26.99	54.63	12.23	3.59	1.03	—	—
All	42	0.04	9.81	35.32	44.47	7.95	1.92	0.46	0.02	0.02

SPAWNING RUNS

23	4	—	7.59	27.13	50.88	12.85	0.50	0.77	0.27	—
24	2	—	22.24	35.70	34.05	6.38	0.55	1.08	—	—
25	4	—	10.62	26.28	45.86	11.20	4.47	1.31	0.27	—
All	10	—	11.73	28.65	45.35	10.89	2.11	1.05	0.21	—

Table VI.—Average Sex Ratio (Females/Males) and Stage of Development for Samples of Commercial Catches and Spawning Runs during the 1950–51 Season

COMMERCIAL CATCHES

Area	Sex Ratio	Percentage		
		Immature	Mature, Unspent	Mature, Spent
23	0.90	5.2	94.8	—
24	1.00	46.5	53.5	—
25	1.13	0.5	99.5	—
All	0.91	7.0	93.0	—

SPAWNING RUNS

23	0.97	—	73.2	26.8
24	0.96	—	74.5	25.5
25	1.16	0.8	80.5	18.8
All	1.04	0.3	76.4	23.3

Table VII.—Average Length (Millimetres) and Average Weight (Grams) for Each Age in Samples from Commercial Catches, with Numbers of Fish on Which Averages Are Based in Parentheses.

AVERAGE LENGTH

In Year of Age	Area 23	Area 24	Area 25	All Areas
I	(1) 142.0	(1) 105.0		(2) 123.5
II	(343) 161.0	(166) 152.7	(3) 163.7	(512) 158.4
III	(1,443) 188.2	(19) 165.2	(53) 189.8	(1,515) 188.0
IV	(1,705) 203.8	(7) 186.7	(107) 200.7	(1,819) 203.6
V	(247) 213.4		(24) 213.7	(269) 215.0
VI	(51) 221.0		(7) 213.1	(58) 220.1
VII	(9) 226.8		(2) 224.0	(11) 226.3
VIII	(1) 242.0			(1) 242.0
IX	(1) 247.0			(1) 247.0
?	(137) 198.3	(7) 158.8	(4) 201.0	(148) 196.6

AVERAGE WEIGHT

I	(1) 33.0	(1) 12.0		(2) 22.5
II	(343) 51.4	(166) 47.7	(3) 56.0	(512) 50.3
III	(1,443) 88.3	(19) 62.5	(53) 90.2	(1,515) 88.0
IV	(1,705) 114.8	(7) 95.3	(107) 109.8	(1,819) 114.4
V	(247) 133.9		(24) 135.3	(269) 135.0
VI	(51) 151.6		(7) 129.4	(58) 148.9
VII	(9) 158.8		(2) 158.5	(11) 158.7
VIII	(1) 205.0			(1) 205.0
IX	(1) 196.0			(1) 196.0
?	(137) 106.1	(7) 54.1	(4) 119.8	(148) 104.7

Table VIII.—Average Length (Millimetres) in Samples from Spawning Runs, with Numbers of Fish on Which Averages Are Based Indicated in Parentheses

In Year of Age	Area 23	Area 24	Area 25	All Areas
II	(29) 167.7	(42) 159.4	(40) 161.7	(111) 162.4
III	(103) 192.3	(68) 187.7	(100) 186.2	(271) 188.9
IV	(190) 208.0	(64) 197.3	(175) 206.9	(429) 205.9
V	(48) 218.5	(12) 211.4	(43) 219.2	(103) 218.0
VI	(2) 221.0	(1) 225.0	(17) 224.2	(20) 224.0
VII	(3) 221.3	(2) 213.5	(5) 222.4	(10) 220.3
VIII	(1) 237.0		(1) 236.0	(2) 236.5
?	(24) 201.3	(11) 192.7	(19) 187.9	(54) 194.8

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CONTRIBUTIONS TO THE LIFE-HISTORY OF THE SOCKEYE SALMON (No. 36)

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INTRODUCTION

The outstanding feature of the 1950 sockeye runs was the large packs in Rivers Inlet, Nass River, and Smith Inlet. Rivers Inlet pack of 142,710 cases was the second heaviest pack recorded for this area. The Nass River pack of 27,286 cases is the highest since 1936. The Smith Inlet pack of 42,435 cases is the highest recorded pack in statistics going back to 1925 (Table XIX). The Skeena pack of 47,479 cases was well below the average of 68,623 cases for the past ten years.

There was a heavy escapement of large sockeye to Rivers Inlet and of predominantly small fish to Smith Inlet. The Nass had a satisfactory escapement, but that to the Skeena was moderate in the upper reaches and light in the lower areas.

DESIGNATION OF AGE-GROUPS

Two outstanding features in the life-history of the fish have been selected in designating the age-groups—namely, the age at maturity and the year of its life in which the fish migrated from fresh water. These are expressed symbolically by two numbers—one in large type, which indicates the age of maturity, and the other in small type, placed to the right and below, which signifies the year of life in which the fish left fresh water. The age-groups which are met most commonly are:—

3_1, 4_1—the "sea-types" or fish which migrate seaward in their first year and mature in their third and fourth year respectively.

3_2—"the grilse," usually males, which migrate seaward in their second year and mature in their third year.

4_2, 5_2—fish which migrate seaward in their second year and mature in their fourth and fifth years respectively.

5_3, 6_3—fish which migrate seaward in their third year and mature in their fifth and sixth years respectively.

6_4, 7_4—fish which migrate seaward in their fourth year and mature in their sixth and seventh years respectively.

1. THE RIVERS INLET SOCKEYE RUN OF 1950

(1) General Characteristics

The pack of sockeye salmon at Rivers Inlet in 1950 was 142,710 cases. The catch was composed chiefly of 5_2 fish (Table I). Thus it is evident that the escapement of 1945 was chiefly responsible for the very large run of 1950. The escapement in 1950, reported to be mainly large fish, would also be of the 5_2 age-class.

(2) Age-groups

Just over 2,000 sockeye from Rivers Inlet were sampled in 1950, and of these, 86.9 per cent were 5_2 fish. While not unprecedented, this is a very high percentage of this age-class for this area. The 4_2 age-class was represented by 261 sockeye or 12.8 per cent

of the catch. These two age-groups formed 99.7 per cent of the catch. Small numbers of 4_1 and 5_3 age-class sockeye were present (Table I).

(3) Lengths and Weights

The average lengths of the males and females of the 4_2 age-group were 21.1 and 20.8 inches respectively; of the 5_2 age-group, 25.2 and 24.2 inches respectively. The average weights of the males and females of the 4_2 age-group were 4.2 and 3.9 pounds respectively; of the 5_2 age-group, 7.5 and 6.4 pounds respectively. Data on the 4_1 and 5_3 age-groups may be found in Tables II and III.

(4) Distribution of Sexes

There were 841 males and 1,199 females in the sample, giving percentages of 41 and 59 respectively. However, 75.1 per cent of the 261 4_2 fish were males and only 24.9 per cent females. In the 5_2 age-group 641 sockeye or 36.2 per cent of the 1,773 fish were males; 1,132 sockeye or 63.8 per cent were females (Table VI). These percentages are not unusual in the sockeye-catch in this area.

2. THE SKEENA RIVER SOCKEYE RUN OF 1950

(1) General Characteristics

The Skeena River sockeye-pack was composed chiefly of 4_2 and 5_2 age-class fish, the latter predominating (Table VII). Smaller numbers of 5_3 and 6_3 age-class fish were present. The pack of 47,479 cases was low and, in addition, spawning was reported as moderate or light in all districts. The escapement to the Babine area was 543,000 sockeye, of which approximately 35 per cent were jacks. This may be compared with the Babine counts of previous years: 1946, 475,700; 1947, 522,500 (approximately 48 per cent jacks); 1948, 560,000;* 1949, 509,100 (approximately 9.5 per cent jacks). It is necessary to note that in the 1949 Report the figure quoted for the Skeena escapement (509,000) was actually only the escapement to the Babine area. The escapement to the whole Skeena watershed in 1949 was about average, with moderately heavy seedings occurring in the upper river and light to medium seedings in the lower river. The estimate quoted for the 1948 escapement in the 1949 Report is considered to be low, although the actual spawning escapement estimates since 1948 are not available. The Fisheries Research Board of Canada has not included such surveys of the whole Skeena watershed in its general programme, and records obtained by Fisheries Department Inspectors have not yet been adequately analysed.

(2) Age-groups

The Skeena sockeye sample in 1950 consisted of 1,511 fish, of which the 4_2 and 5_2 age-classes made up 93.5 per cent, the latter predominating with 1,092 fish or 72.3 per cent. The 5_3 and 6_3 age-groups were represented by 53 and 42 sockeye respectively or percentages of 3.5 and 2.8 (Table VII). The 4_1, 3_2, and 6_2 age-classes were each represented by one fish. The 4_1 sockeye, a female, was 23.5 inches long and weighed 5.1 pounds; the 3_2 fish was a male 14 inches long and weighed 1.2 pounds; and the 6_2 sockeye, also a male, was 26.5 inches long and weighed 8.3 pounds.

(3) Lengths and Weights

Though the Skeena sockeye were not numerous in 1950, their average length was close to the maximum recorded for the area. The males and females of the 4_2 age-class had average lengths of 22.8 and 22.3 inches respectively; those of the 5_2 age-group were 25.7 and 24.4 inches respectively; and the 5_3 age-group had average lengths of 23.9 and

* This figure is an estimate, as the Babine fence was not operating in 1948.

23.4 inches respectively for the males and females. The 6_3 age-class, however, was nearer the normal length for that group, with the males averaging 25.5 inches and the females 24.3 inches. The 4_2 age-class, males and females, had low average weights in comparison with past years, being respectively 4.8 and 4.3 pounds. In the 5_2 age-group, however, the males, with an average of 7.2 pounds, were relatively heavy, while the females, averaging 5.9 pounds, were relatively light. In the 5_3 age-class both the males and females, with averages of 5.8 pounds and 5.1 pounds, were comparatively heavy. However, fish in the 6_3 age-class were comparatively light, the males and females averaging 6.8 and 5.6 pounds respectively (Tables VIII, IX, X, and XI).

(4) Distribution of Sexes

Of the 1,511 sockeye in the Skeena sample, 664 or 43.9 per cent were males and 847 or 56.1 per cent were females. These percentages were reversed for the 4_2 age-group, 56 per cent being males and 44 per cent females. In the 5_2 age-class 40 per cent were males and 60 per cent females. The 5_3 age-class sex ratio was similar to the 4_2 age-class, with 53 per cent males and 47 per cent females, while the percentages of males and females in the 6_3 age-class were 40 per cent and 60 per cent respectively; that is, the same as the 5_2 age-group (Table XII).

3. THE NASS RIVER SOCKEYE RUN OF 1950

(1) General Characteristics

The Nass River sockeye-pack of 27,286 cases was the largest since 1936. It was composed chiefly of 5_3 age-class salmon, with the 5_2 and 6_3 age-classes being the only other groups present in significant numbers. Thus it is seen that the large pack was due to the return from the 1945 seeding.

The escapement was reported as satisfactory on the Nass River in 1950.

(2) Age-groups

Of the 2,280 sockeye in the Nass River sample, 1,624 or 71.2 per cent were from the 5_3 age-class; 441 or 19.3 per cent were from the 5_2 age-class; 139 or 6.1 per cent were from the 6_3 age-group; and 69 or 3.0 per cent were from the 4_2 age-class (Table XIII). The 4_1 age-class was represented by 7 fish or 0.3 per cent of the run.

(3) Lengths and Weights

The lengths and weights of the Nass River sockeye as shown in the tables are not unusual for this run. The 5_3 age-group had average lengths of 24.5 and 23.7 inches respectively for the males and females, and the 5_2 age-class 26.0 and 24.7 inches respectively. The lengths for the 6_3, 4_2, and 4_1 age-classes, males and females, were 26.7 and 25.6, 23.6 and 23.1, and 25.0 and 23.3 inches respectively (Tables XIV and XVI). The weights of the different age-classes, males and females, were as follows: 4_2 age-group, 5.9 and 5.2 pounds; 5_2 age-group, 7.9 and 6.6 pounds; 5_3 age-group, 6.4 and 5.5 pounds; and the 6_3 age-class, 8.2 and 7.1 pounds respectively (Tables XV and XVII). There is nothing out of the ordinary about these weights.

(4) Distribution of Sexes

Of the 2,280 sockeye in the sample, 993 or 43.6 per cent were males and 1,287 or 56.4 per cent were females. This ratio held for all the main age-groups except the 6_3 class, where it was reversed, 58 per cent being males and 42 per cent females (Table XVIII).

4. THE SMITH INLET SOCKEYE RUN FOR 1950

(1) General Characteristics

Though the Smith Inlet sockeye have been sampled since 1945, the results have not previously been included in this series. Most of the previous work on these fish has been done by J. G. Robertson, of this station, and A. Andrekson, formerly of this station. Results of their studies appeared in the Progress Reports of the Pacific Coast Stations, Fisheries Research Board of Canada, No. 75, July, 1948, and No. 82, April, 1950. The arrangements for sampling the run have been made by the Dominion Fisheries Department Inspector for the Rivers Inlet-Smith Inlet area.

From Table XIX it is seen that the run since 1945 has been predominantly either 4_2 or 5_2 age-class fish, percentages varying from 5 per cent to over 90 per cent for both these groups. The pack has varied from a low of 3,165 in 1944 to a high of 42,435 cases for 1950. However, the former pack was low due to protective measures taken by the Dominion Fisheries Department and thus is not an indication of the size of the run in that year.

(2) Age-groups

As mentioned above, the Smith Inlet sockeye, at least since 1945, consisted chiefly of 4_2 and 5_2 age-classes (Table XIX). In none of these years have all other age-classes combined amounted to as much as 5 per cent of the total sample. In 1950 the 5_2 age-class was represented by 406 fish or 82.9 per cent of the sample and the 4_2 age-class by 83 fish or 16.9 per cent of the sample. One 5_3 fish was present in the sample of 490 sockeye.

(3) Lengths and Weights

The average length and weight of the Smith Inlet sockeye sample was 23.9 inches and 6.5 pounds. The 5_2 age-class averaged 24.3 inches and 6.9 pounds. The males in the 5_2 age-class averaged 24.8 inches and 7.4 pounds and the females 24.0 inches and 6.6 pounds. The 4_2 age-class, males and females, averaged 21.6 inches and 4.9 pounds and 21.7 inches and 5.0 pounds respectively and with the sexes combined averaged 21.6 inches and 4.9 pounds (Tables XX and XXI). A peculiarity, noticed in three out of the six years in which sampling has been done in this area, is the tendency of the female fish of the 4_2 age-class to be both longer and heavier than the males (Tables XXII and XXIII).

(4) Distribution of Sexes

The sex ratio of the Smith Inlet sockeye sample has, during the past six years, varied from 77 to 41 per cent males and from 23 to 59 per cent females. The 49:51 ratio of males to females in 1950 is the closest to equality of sexes recorded in the sampling (Table XXIV). It is not known to what extent, if any, gill-net selectivity affects the sex ratio in the catch for this area.

Table I.—Rivers Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1907 (87,874 cases)	...	—	—	—
1908 (64,652 cases)	—	—	—	—
1909 (89,027 cases)	—	—	—	—
1910 (126,921 cases)	—	—	—	—
1911 (88,763 cases)	—	—	—	—
1912 (112,884 cases)	21	79	—	—
1913 (61,745 cases)	80	20	—	—
1914 (89,890 cases)	35	65	—	—
1915 (130,350 cases)	13	87	—	—
1916 (44,936 cases)	26	74	—	—
1917 (61,195 cases)	39	61	—	—
1918 (53,401 cases)	57	43	—	—
1919 (56,258 cases)	46	54	—	—
1920 (121,254 cases)	5	95	—	—
1921 (46,300 cases)	49	51	—	—
1922 (60,700 cases)	81	18	1	—
1923 (107,174 cases)	74	24	2	—
1924 (94,891 cases)	43	54	2	1
1925 (159,554 cases)	23	77	—	—
1926 (65,581 cases)	59	38	2	1
1927 (64,461 cases)	81	16	3	—
1928 (60,044 cases)	55	40	4	1
1929 (70,260 cases)	77	18	3	2
1930 (119,170 cases)	49	48	2	1
1931 (76,428 cases)	53	44	2	1
1932 (69,732 cases)	67	27	5	1
1933 (83,507 cases)	44	55	1	—
1934 (76,923 cases)	77	20	2	1
1935 (135,038 cases)	57	41	1	1
1936 (46,351 cases)	53	46	1	—
1937 (84,832 cases)	60	37	3	—
1938 (87,942 cases)	27	70	1	2
1939 (54,143 cases)	67	32	1	—
1940 (63,469 cases)	69	28	3	—
1941 (93,378 cases)	59	40	1	—
1942 (79,199 cases)	8	91	—	1
1943 (47,602 cases)	8	91	—	1
1944 (36,852 cases)	76	23	1	—
1945 (89,735 cases)	57	41	2	—
1946 (73,320 cases)	37	63	—	—
1947 (140,087 cases)	3	97	—	—
1948 (37,665 cases)	55	44	1	—
1949 (39,495 cases)	84	14	1	—
1950 (142,710 cases)	13	87	(1)	—

[1] Age-class represented but less than 0.5 per cent.

Table II.—Rivers Inlet Sockeyes, 1950, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals										Total
	4_1		4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
17	—	—	1	—	—	—	—	—	—	—	1
17¼	—	—	—	—	—	—	—	—	—	—	—
17½	—	—	—	—	—	—	—	—	—	—	—
17¾	—	—	—	—	—	—	—	—	—	—	—
18	—	—	4	—	—	—	—	—	—	—	4
18¼	—	—	—	—	—	—	—	—	—	—	—
18½	—	—	2	—	—	—	—	—	—	—	2
18¾	—	—	—	—	—	—	—	—	—	—	—
19	—	—	9	3	—	—	—	—	—	—	12
19¼	—	—	1	2	—	—	—	—	—	—	3
19½	—	—	11	4	—	—	—	—	—	—	15
19¾	—	—	6	3	—	—	—	—	—	—	9
20	—	—	16	7	—	1	—	—	—	—	24
20¼	—	—	9	3	—	—	—	—	—	—	12
20½	—	—	15	5	—	—	—	—	—	—	20
20¾	—	—	7	7	—	—	—	—	—	—	14
21	—	—	25	14	1	5	—	—	—	—	45
21¼	—	—	11	2	2	1	—	—	—	—	16
21½	—	—	8	1	—	11	—	—	—	—	20
21¾	—	—	6	—	1	4	—	—	—	—	11
22	—	—	29	6	8	39	1	—	—	—	83
22¼	—	—	5	4	3	13	1	—	—	—	26
22½	—	—	7	1	10	37	—	—	—	—	55
22¾	—	—	4	—	6	18	—	—	—	—	28
23	—	1	6	1	27	106	1	—	—	—	142
23¼	—	—	1	—	6	29	—	—	—	—	36
23½	—	—	6	—	21	70	—	—	—	—	97
23¾	—	—	1	1	8	43	—	—	—	—	53
24	—	—	3	1	49	171	—	—	—	—	224
24¼	—	—	—	—	14	55	—	—	—	—	69
24½	—	—	2	—	44	122	—	—	—	—	168
24¾	—	—	—	—	24	60	—	—	—	—	84
25	—	—	—	—	83	165	—	1	—	—	249
25¼	—	—	1	—	30	37	—	—	—	—	68
25½	—	—	—	—	55	62	—	—	—	—	117
25¾	—	—	—	—	34	24	—	—	—	—	58
26	—	—	—	—	78	42	—	—	—	—	120
26¼	—	—	—	—	19	4	—	—	—	—	23
26½	1	—	—	—	39	7	—	—	—	—	47
26¾	—	—	—	—	20	4	—	—	—	—	24
27	—	—	—	—	34	1	—	—	—	—	35
27¼	—	—	—	—	4	—	—	—	—	—	4
27½	—	—	—	—	10	1	—	—	—	—	11
27¾	—	—	—	—	4	—	—	—	—	—	4
28	—	—	—	—	4	—	—	—	—	—	4
28¼	—	—	—	—	1	—	—	—	—	—	1
28½	—	—	—	—	1	—	—	—	—	—	1
28¾	—	—	—	—	1	—	—	—	—	—	1
Totals	1	1	196	65	641	1,132	3	1	—	—	2,040
Average lengths	26.5	23.0	21.1	20.8	25.2	24.2	22.4	25.0	—	—	24.1

Table III.—Rivers Inlet Sockeyes, 1950, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals										Total
	4_1		4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
2			2								2
2¼			1								1
2½			1								1
2¾			3	2		1					6
3			21	6							27
3¼			14	10	1	1					26
3½			17	5	2	3					27
3¾			16	10	1	5	1				33
4			26	10	1	17					54
4¼			19	8	2	12	1				42
4½			21	5	3	25					54
4¾			13	4	7	21					45
5			13	3	14	47					77
5¼		1	10	1	13	53					78
5½			9		17	88					114
5¾			3		20	76	1				100
6			3		35	133					171
6¼			2		29	93					124
6½			1	1	29	107					138
6¾					32	63					95
7			1		59	111					171
7¼					41	77					118
7½					50	69		1			120
7¾					30	39					69
8					55	42					97
8¼					38	15					53
8½	1				31	15					47
8¾					26	8					34
9					36	6					42
9¼					17	3					20
9½					13	1					14
9¾					6						6
10					14	1					15
10¼					11						11
10½					3						3
10¾					2						2
11											
11¼					1						1
11½											
11¾					1						1
12					1						1
Totals	1	1	196	65	641	1,132	3	1			2,040
Average weights	8.5	5.3	4.2	3.9	7.5	6.4	4.6	7.5			6.4

Table IV.—Rivers Inlet Sockeyes, Average Lengths in Inches of the 4_2 and 5_2 Groups, 1912 to 1950

Year	4_2		5_2	
	M.	F.	M.	F.
1912–41	22.4	22.4	25.4	24.7
1912–41 (conversion)	21.6	21.6	24.6	23.9
1942	21.9	21.3	25.0	23.8
1943	20.5	21.1	24.3	23.7
1944	21.1	21.0	23.5	23.3
1945	20.9	21.2	24.2	23.9
1946	20.6	21.1	25.1	24.1
1947	20.6	20.7	24.0	23.5
1948	21.4	21.3	25.2	24.2
1949	20.9	21.4	23.8	22.8
1950	21.1	20.8	25.2	24.2

Table V.—Rivers Inlet Sockeyes, Average Weights in Pounds of the 4_2 and 5_2 Groups, 1914 to 1950

Year	4_2		5_2	
	M.	F.	M.	F.
1914–41	4.9	4.8	7.0	6.5
1942	5.1	4.6	7.2	6.4
1943	4.1	4.4	6.8	6.3
1944	4.6	4.4	6.2	6.0
1945	4.3	4.4	6.6	6.4
1946	3.9	3.9	7.2	6.2
1947	4.1	3.9	6.4	5.9
1948	4.7	4.6	7.9	7.0
1949	4.4	4.3	5.9	5.9
1950	4.2	3.9	7.5	6.4

Table VI.—Rivers Inlet Sockeyes, Percentages of Males and Females, 1915 to 1950

Year	4_1		4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.		
1915–41 (average)	....	....	63	37	34	66	50	50
1942	....	....	61	39	35	65	38	62
1943	....	....	62	38	34	66	36	64
1944	....	....	67	33	33	67	59	41
1945	....	....	70	30	39	61	57	43
1946	....	....	79	21	37	63	53	47
1947	....	....	72	28	35	65	36	64
1948	....	....	50	50	38	62	45	55
1949	36	64	70	30	22	78	63	37
1950	50	50	75	25	36	64	41	59

Table VII.—Skeena River Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1907 (108,413 cases)	....	....	....	....
1908 (139,846 cases)	....	....	....	....
1909 (87,901 cases)				
1910 (187,246 cases)	....	....	....	....
1911 (131,066 cases)	....	....	....	....
1912 (92,498 cases)	57	43	....	....
1913 (52,927 cases)	50	50		
1914 (130,166 cases)	25	75		
1915 (116,553 cases)	36	64		....
1916 (60,923 cases)	34	38	13	18
1917 (65,760 cases)	57	29	9	5
1918 (123,322 cases)	51	34	9	6
1919 (184,945 cases)	27	60	9	4
1920 (90,869 cases)	15	71	6	8
1921 (41,018 cases)	69	22	6	3
1922 (96,277 cases)	70	16	12	2
1923 (131,731 cases)	56	29	8	7
1924 (144,747 cases)	23	69	7	1
1925 (77,784 cases)	51	45	3	1
1926 (82,360 cases)	62	26	9	3
1927 (83,996 cases)	62	28	9	1
1928 (34,559 cases)	51	39	7	3
1929 (78,017 cases)	62	30	6	2
1930 (132,372 cases)	39	52	8	1
1931 (93,023 cases)	40	30	28	2
1932 (59,916 cases)	44	37	7	12
1933 (30,506 cases)	57	36	5	2
1934 (54,558 cases)	58	34	7	1
1935 (52,879 cases)	49	31	18	2
1936 (81,973 cases)	67	20	11	2
1937 (42,491 cases)	45	40	11	4
1938 (47,257 cases)	64	15	16	5
1939 (68,485 cases)	50	35	11	4
1940 (116,507 cases)	80	15	4	1
1941 (81,767 cases)	39	52	8	1
1942 (34,544 cases)	36	54	7	3
1943 (28,268 cases)	39	39	16	6
1944 (68,197 cases)	37	52	7	4
1945 (104,279 cases)	20	63	12	5
1946 (52,928 cases)	13	70	8	9
1947 (32,534 cases)	14	82	3	1
1948 (101,267 cases)	80	13	6	1
1949 (65,937 cases)	17	76	4	3
1950 (47,479 cases)	21	72	4	3

Table VIII.—Skeena River Sockeyes, 1950, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals											Total
	4_2		5_2		5_3		6_3		Other Age-classes			
	M.	F.	M.	F.	M.	F.	M.	F.	Age	M.	F.	
14	—	—	—	—	—	—	—	—	3_2	1	—	1
18¾	1	—	—	—	—	—	—	—	—	—	—	1
19	1	—	—	—	—	—	—	—	—	—	—	1
19¼	—	—	—	—	—	—	—	—	—	—	—	—
19½	—	—	—	—	—	—	—	—	—	—	—	—
19¾	1	—	—	—	—	—	—	—	—	—	—	1
20	—	1	—	—	—	—	—	—	—	—	—	1
20¼	3	—	—	—	—	1	—	—	—	—	—	4
20½	2	1	—	—	1	—	—	—	—	—	—	4
20¾	1	—	—	—	—	—	—	—	—	—	—	1
21	5	4	—	1	1	—	—	—	—	—	—	11
21¼	4	6	—	—	—	—	—	—	—	—	—	10
21½	4	16	—	—	—	—	—	—	—	—	—	20
21¾	2	17	—	—	—	1	—	—	—	—	—	20
22	14	21	—	4	—	1	—	—	—	—	—	40
22¼	17	17	2	5	—	—	—	—	—	—	—	41
22½	16	16	1	10	2	3	—	—	—	—	—	48
22¾	15	7	2	7	1	1	—	1	—	—	—	34
23	23	15	3	26	2	4	—	1	—	—	—	74
23¼	15	6	2	20	1	1	—	—	—	—	—	45
23½	21	8	5	54	2	1	—	4	4_1	—	1	96
23¾	8	3	8	56	1	3	—	1	—	—	—	80
24	8	2	17	88	4	3	1	4	—	—	—	127
24¼	7	1	14	49	1	2	1	2	—	—	—	77
24½	5	—	15	68	2	1	2	2	—	—	—	95
24¾	2	—	10	58	2	—	—	4	—	—	—	76
25	2	—	46	68	3	1	3	5	—	—	—	128
25¼	1	—	32	46	3	1	2	—	—	—	—	85
25½	1	—	28	58	1	1	—	1	—	—	—	90
25¾	—	—	28	17	—	—	—	—	—	—	—	45
26	1	—	65	18	1	—	4	—	—	—	—	89
26¼	—	—	39	6	—	—	2	—	—	—	—	47
26½	—	—	38	2	—	—	—	—	6_2	1	—	41
26¾	—	—	25	2	—	—	1	—	—	—	—	28
27	—	—	22	1	—	—	—	—	—	—	—	23
27¼	—	—	8	1	—	—	—	—	—	—	—	9
27½	—	—	11	—	—	—	1	—	—	—	—	12
27¾	—	—	3	—	—	—	—	—	—	—	—	3
28	—	—	9	—	—	—	—	—	—	—	—	9
28¼	—	—	3	—	—	—	—	—	—	—	—	3
28½	—	—	1	—	—	—	—	—	—	—	—	1
Totals	180	141	437	655	28	25	17	25	—	2	1	1,511
Average lengths	22.8	22.3	25.7	24.4	23.9	23.4	25.5	24.3	—	—	—	24.4

Table IX.—Skeena River Sockeyes, 1950, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals											Total
	4_2		5_2		5_3		6_3		Other Age-classes			
	M.	F.	M.	F.	M.	F.	M.	F.	Age	M.	F.	
1¼	.....	.....	—	—	—	—	—	—	3_2	1	—	1
1½	.....	.....	—	—	—	—	—	—	—	—	—	—
1¾	.....	.....	—	—	—	—	—	—	—	—	—	—
2	.....	.....	—	—	—	—	—	—	—	—	—	—
2¼	1	—	—	—	—	—	—	—	—	—	—	1
2½	1	.....	—	—	—	—	—	—	—	—	—	1
2¾	1	.....	—	—	—	—	—	—	—	—	—	1
3	.....	.....	—	—	1	1	—	—	—	—	—	2
3¼	2	2	.....	—	—	1	—	—	—	—	—	5
3½	10	15	—	—	—	1	—	—	—	—	—	26
3¾	10	21	—	—	—	—	—	—	—	—	—	31
4	22	26	—	10	1	2	—	—	—	—	—	61
4¼	15	14	—	14	1	2	—	—	—	—	—	46
4½	24	24	2	26	2	2	—	1	—	—	—	81
4¾	13	16	6	30	1	2	—	1	—	—	—	69
5	23	11	9	69	1	2	—	5	4_1	—	1	121
5¼	11	2	7	51	2	1	1	2	—	—	—	77
5½	13	4	14	84	3	2	—	2	—	—	—	122
5¾	7	3	11	42	2	2	—	4	—	—	—	71
6	13	2	31	81	2	4	3	6	—	—	—	142
6¼	3	1	27	36	2	2	2	3	—	—	—	76
6½	2	—	35	59	2	—	2	—	—	—	—	100
6¾	5	—	34	48	2	—	2	—	—	—	—	91
7	3	—	53	36	3	—	2	1	—	—	—	98
7¼	1	—	24	22	.....	.....	1	.....	.....	.....	.....	48
7½	.....	.....	40	22	3	1	—	—	—	—	—	66
7¾	.....	.....	25	11	—	—	2	—	—	—	—	38
8	.....	.....	27	9	—	—	—	—	—	—	—	36
8¼	.....	.....	17	2	—	—	1	—	6_2	1	—	21
8½	.....	.....	20	1	—	—	—	—	—	—	—	21
8¾	.....	.....	14	1	—	—	—	—	—	—	—	15
9	.....	.....	14	1	—	—	1	—	—	—	—	16
9¼	.....	—	10	—	—	—	—	—	—	—	—	10
9½	.....	—	5	—	—	—	—	—	—	—	—	5
9¾	.....	—	1	—	—	—	—	—	—	—	—	1
10	.....	.....	7	.....	.....	.....	.....	.....	.....	.....	.....	7
10¼	—	—	2	—	—	—	—	—	—	—	—	2
10½	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10¾	—	—	2	—	—	—	—	—	—	—	—	2
Totals	180	141	437	655	28	25	17	25	.....	2	1	1,511
Average weights	4.8	4.3	7.2	5.9	5.8	5.1	6.8	5.6	.....	.....	.....	6.0

Table X.—Skeena River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1950

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	23.7	23.1	25.8	24.9	24.2	23.4	25.8	24.8
1912–41 (conversion)	23.0	22.4	25.1	24.2	23.5	22.7	25.1	24.1
1942	22.6	22.3	25.2	24.3	24.1	23.7	26.3	24.9
1943	21.9	21.9	25.1	23.9	23.3	22.6	25.8	24.7
1944	22.4	21.7	24.8	23.9	22.5	21.7	25.0	23.7
1945	22.6	22.3	24.9	24.1	23.3	22.6	25.0	24.3
1946	22.7	22.0	25.4	24.3	23.9	23.2	25.5	24.4
1947	22.3	22.0	25.1	23.8	23.0	22.4	26.3	25.8
1948	23.0	22.3	25.3	24.1	23.0	22.1	26.0	24.5
1949	22.5	22.2	25.3	24.5	23.2	22.3	24.8	23.9
1950	22.8	22.3	25.7	24.4	23.9	23.4	25.5	24.3

Table XI.—Skeena River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1950

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	5.4	5.0	6.8	6.1	5.7	5.1	6.8	6.0
1942	4.9	4.7	6.7	6.0	5.8	5.4	7.2	6.6
1943	4.7	4.6	6.8	5.9	5.5	4.9	7.3	6.1
1944	5.1	4.6	7.0	6.1	5.3	4.6	7.1	5.8
1945	5.2	4.9	6.7	6.1	5.6	5.0	6.7	6.2
1946	4.7	4.2	6.9	5.8	5.8	5.1	7.0	6.1
1947	4.9	4.7	6.9	5.9	5.3	5.0	7.7	6.8
1948	5.5	4.9	7.3	6.1	5.4	4.7	7.7	6.4
1949	5.0	4.7	7.1	6.3	5.3	4.8	6.6	5.7
1950	4.8	4.3	7.2	5.9	5.8	5.1	6.8	5.6

Table XII.—Skeena River Sockeyes, Percentages of Males and Females, 1915 to 1950

Year	4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.		
1915–41 (average)	48	52	43	57	46	54
1942	42	58	25	75	33	67
1943	50	50	31	69	43	57
1944	54	46	34	66	43	57
1945	41	59	35	65	38	62
1946	50	50	32	68	38	62
1947	50	50	29	71	33	67
1948	50	50	29	71	47	53
1949	54	46	30	70	36	64
1950	56	44	40	60	44	56

Table XIII.—Nass River Sockeyes, Percentages of Principal Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1912 (36,037 cases)	8	27	63	2
1913 (23,574 cases)	15	12	71	2
1914 (31,327 cases)	4	41	45	10
1915 (39,349 cases)	19	14	59	8
1916 (31,411 cases)	9	17	66	8
1917 (22,188 cases)	10	15	71	4
1918 (21,816 cases)	30	16	45	9
1919 (28,259 cases)	7	22	65	6
1920 (16,740 cases)	8	14	72	6
1921 (9,364 cases)	10	7	75	8
1922 (31,277 cases)	6	2	91	1
1923 (17,821 cases)	11	6	77	6
1924 (33,590 cases)	4	3	91	2
1925 (18,945 cases)	23	8	67	2
1926 (15,929 cases)	12	12	63	13
1927 (12,026 cases)	8	7	81	4
1928 (5,540 cases)	30	6	61	3
1929 (16,077 cases)	25	9	60	6
1930 (26,405 cases)	28	15	54	3
1931 (16,929 cases)	10	17	67	6
1932 (14,154 cases)	28	4	61	7
1933 (9,757 cases)	35	7	55	3
1934 (36,242 cases)	13	9	74	4
1935 (12,712 cases)	11	10	73	6
1936 (28,562 cases)	16	7	67	10
1937 (17,567 cases)	22	4	68	6
1938 (21,462 cases)	21	4	70	5
1939 (24,357 cases)	14	13	66	7
1940 (13,809 cases)	23	8	59	10
1941 (24,876 cases)	37	7	52	4
1942 (21,085 cases)	22	7	66	5
1943 (13,412 cases)	5	13	67	15
1944 (13,083 cases)	15	15	32	38
1945 (9,899 cases)	46	11	37	6
1946 (12,511 cases)	13	12	72	3
1947 (10,849 cases)	15	12	56	17
1948 (13,181 cases)	12	16	60	12
1949 (9,268 cases)	39	6	48	7
1950 (27,286 cases)	3	19	71	6

Table XIV.—Nass River Sockeyes, 1950, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals										Total
	4_1		4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
19¾	—	—	—	1	—	—	—	—	—	—	1
20	—	—	—	—	—	—	—	1	—	—	1
20¼	—	—	—	—	—	—	—	—	—	—	—
20½	—	—	—	—	—	—	—	—	—	—	—
20¾	—	—	—	—	—	—	—	1	—	—	1
21	—	—	—	1	—	—	—	—	—	—	1
21¼	—	—	—	1	—	—	—	1	—	—	2
21½	—	—	—	—	—	1	—	2	—	—	3
21¾	—	—	—	2	—	—	2	6	—	—	10
22	—	—	—	—	1	—	3	23	—	—	27
22¼	—	—	4	3	—	1	5	20	—	—	33
22½	—	—	3	5	—	1	9	56	—	—	74
22¾	—	—	1	3	—	2	8	60	—	—	74
23	—	1	5	6	1	7	22	105	—	—	147
23¼	—	2	1	4	1	12	33	81	1	1	136
23½	—	1	2	4	2	18	54	98	1	—	180
23¾	—	—	2	2	—	12	43	90	—	—	149
24	—	—	1	3	1	28	81	105	1	7	227
24¼	—	—	—	3	5	13	61	64	2	2	150
24½	—	—	4	1	9	29	83	71	1	3	201
24¾	—	—	2	—	3	20	60	40	1	4	130
25	3	—	1	1	13	37	57	46	2	2	162
25¼	—	—	—	1	7	15	45	20	2	5	95
25½	—	—	1	—	19	22	51	15	6	5	119
25¾	—	—	1	—	13	7	17	8	3	5	54
26	—	—	—	—	22	7	23	10	3	7	72
26¼	—	—	—	—	20	8	12	4	4	4	52
26½	—	—	—	—	19	6	11	2	7	1	46
26¾	—	—	—	—	9	3	11	—	5	1	29
27	—	—	—	—	11	1	4	—	10	4	30
27¼	—	—	—	—	10	2	—	—	7	2	21
27½	—	—	—	—	6	1	—	—	5	—	12
27¾	—	—	—	—	9	—	—	—	5	4	18
28	—	—	—	—	3	1	—	—	4	1	9
28¼	—	—	—	—	1	—	—	—	4	—	5
28½	—	—	—	—	—	1	—	—	2	—	3
28¾	—	—	—	—	1	—	—	—	2	—	3
29	—	—	—	—	—	—	—	—	2	—	2
29¼	—	—	—	—	—	—	—	—	1	—	1
Totals	3	4	28	41	186	255	695	929	81	58	2,280
Average lengths	25.0	23.3	23.6	23.1	26.0	24.7	24.5	23.7	26.7	25.6	24.4

Table XV.—Nass River Sockeyes, 1950, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals										Total
	4_1		4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
3	—	—	—	—	—	—	—	1	—	—	1
3¼	—	—	—	1	—	—	—	1	—	—	2
3½	—	—	—	1	—	1	—	8	—	—	10
3¾	—	—	—	1	—	1	—	6	—	—	8
4	—	—	—	2	—	—	2	22	—	—	26
4¼	—	—	1	3	1	1	9	21	—	—	36
4½	—	—	—	2	2	4	10	66	—	1	85
4¾	—	—	1	—	—	1	10	64	—	—	76
5	—	—	2	6	—	10	22	108	1	—	149
5¼	—	—	4	5	1	5	24	101	1	2	143
5½	—	2	3	8	—	23	61	159	1	1	258
5¾	—	—	1	2	1	10	56	76	1	1	148
6	—	2	5	7	5	26	87	109	—	5	246
6¼	—	—	3	—	3	19	75	45	—	5	150
6½	—	—	3	2	10	34	99	69	4	6	227
6¾	1	—	1	—	3	27	53	29	2	5	121
7	1	—	3	1	16	27	55	25	3	6	137
7¼	—	—	—	—	13	17	34	7	4	3	78
7½	—	—	1	—	23	18	48	5	6	4	105
7¾	—	—	—	—	12	8	17	4	3	4	48
8	1	—	—	—	15	12	15	3	11	1	58
8¼	—	—	—	—	10	5	6	—	4	5	30
8½	—	—	—	—	24	—	8	—	6	3	41
8¾	—	—	—	—	14	1	—	—	10	4	29
9	—	—	—	—	9	1	3	—	5	1	19
9¼	—	—	—	—	4	1	1	—	2	—	8
9½	—	—	—	—	7	1	—	—	10	1	19
9¾	—	—	—	—	4	—	—	—	4	—	8
10	—	—	—	—	4	—	—	—	—	—	4
10¼	—	—	—	—	2	1	—	—	—	—	3
10½	—	—	—	—	3	1	—	—	3	—	7
Totals	3	4	28	41	186	255	695	929	81	58	2,280
Average weights	7.3	5.7	5.9	5.2	7.9	6.6	6.4	5.5	8.2	7.1	6.2

Table XVI.—Nass River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1950

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	24.5	23.7	26.3	25.2	26.1	25.3	27.7	26.4
1912–41 (conversion)	23.8	23.0	25.6	24.5	25.4	24.6	27.0	25.7
1942	23.9	23.2	26.1	24.9	24.9	24.3	26.9	26.0
1943	22.8	22.2	26.1	24.8	24.1	23.5	27.1	25.8
1944	23.5	22.7	25.7	24.6	24.8	23.8	26.8	25.8
1945	23.4	22.8	25.0	24.4	24.7	24.0	25.1	25.5
1946	23.4	22.4	26.3	24.9	24.9	23.9	28.1	26.0
1947	23.4	22.9	25.9	24.1	24.5	23.6	27.0	25.6
1948	23.3	22.6	26.2	25.3	25.0	24.1	27.7	26.7
1949	23.8	22.8	26.2	23.8	24.7	23.7	26.1	25.5
1950	23.6	23.1	26.0	24.7	24.5	23.7	26.7	25.6

Table XVII.—Nass River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1950

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	6.0	5.4	7.3	6.4	6.9	6.2	8.0	7.0
1942	5.8	5.1	7.1	6.3	6.2	5.6	7.5	6.7
1943	5.2	4.7	7.6	6.4	5.9	5.3	7.9	6.9
1944	5.7	5.0	7.7	6.5	6.7	5.7	8.2	7.1
1945	5.7	5.3	7.0	6.4	6.5	5.9	7.2	7.1
1946	5.6	4.9	8.1	6.7	6.5	5.4	8.9	7.0
1947	5.8	5.3	7.7	6.2	6.3	5.6	8.1	6.9
1948	5.8	5.3	8.1	7.1	7.0	6.0	9.1	7.9
1949	5.9	5.1	7.9	5.8	6.5	5.4	7.7	6.8
1950	5.9	5.2	7.9	6.6	6.4	5.5	8.2	7.1

Table XVIII.—Nass River Sockeyes, Percentages of Males and Females, 1915 to 1950

Year	4_2		5_2		5_3		6_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.		
1915–41 (average)	49	51	47	53	45	55	63	37	47	53
1942	42	58	48	52	44	56	70	30	45	55
1943	51	49	67	33	47	53	74	26	54	46
1944	53	47	45	55	39	61	60	40	50	50
1945	37	63	37	63	38	62	53	47	38	62
1946	62	38	59	41	45	55	75	25	50	50
1947	50	50	52	48	51	49	81	19	56	44
1948	45	55	54	46	52	48	66	34	53	47
1949	57	43	56	44	51	49	50	50	53	47
1950	41	59	42	58	43	57	58	42	44	56

Table XIX.—Smith Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals				
	4_1	4_2	5_2	6_2	5_3
1925 (33,764 cases)	....	....	....	....	....
1926 (17,921 cases)	....	....	....	....	....
1927 (22,682 cases)	....	....	....	....	....
1928 (33,442 cases)	....	....	....	....	....
1929 (9,683 cases)	....	....	....	....	....
1930 (32,057 cases)	....	....	....	....	....
1931 (12,867 cases)	....	....	....	....	....
1932 (25,488 cases)	....	....	....	....	....
1933 (37,369 cases)	....	....	....	....	....
1934 (14,607 cases)	....	....	....	....	....
1935 (31,648 cases)	....	....	....	....	....
1936 (12,788 cases)	....	....	....	....	....
1937 (25,258 cases)	....	....	....	....	....
1938 (33,894 cases)	....	....	....	....	....
1939 (17,833 cases)	....	....	....	....	....
1940 (25,947 cases)	....	....	....	....	....
1941 (21,495 cases)	....	....	....	....	....
1942 (15,939 cases)	....	....	....	....	....
1943 (15,010 cases)	....	....	....	....	....
1944 (3,165 cases)	....	....	....	....	....
1945 (15,014 cases)	....	50	50	....	....
1946 (14,318 cases)	....	11	89	....	....
1947 (36,800 cases)	....	5	95	....	....
1948 (10,456 cases)	....	7	90	3	....
1949 (13,189 cases)	2	92	5	....	(1)
1950 (42,435 cases)	....	17	83	....	(1)

[1] This age-class was represented by less than 0.5 per cent of the number of fish in the sample.

Table XX.—Smith Inlet Sockeyes, 1950, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
19¾	3	1	—	—	—	—	3
20	—	1	—	—	—	—	1
20¼							
20½	5	—	—	—	1	—	6
20¾	4	—	—	1	—	—	5
21	5	1	—	—	—	—	6
21¼	10	3	—	—	—	—	13
21½	7	2	2	1	—	—	12
21¾	9	1	—	—	—	—	10
22	13	1	—	1	—	—	15
22¼	6	1	2	2	—	—	11
22½	4	1	2	4	—	—	11
22¾	1	—	1	8	—	—	10
23	2	—	4	19	—	—	25
23¼	1	—	2	19	—	—	22
23½	—	—	5	25	—	—	30
23¾	—	—	7	18	—	—	25
24	—	1	17	24	—	—	42
24¼	—	—	10	29	—	—	39
24½		—	19	30	—	—	49
24¾	1	—	11	19	—	—	31
25	—	—	26	20	—	—	46
25¼		—	17	6	—	—	23
25½	—	—	16	7	—	—	23
25¾	—	—	7	2	—	—	9
26	—	—	7	1	—	—	8
26¼		—	6	—	—	—	6
26½	—	—	6	—	—	—	6
26¾	—	—	1	—	—	—	1
27	—	—	1	1	—	—	2
Totals	71	12	169	237	1	—	490
Average lengths	21.6	21.7	24.8	24.0	20.5	—	23.9

Table XXI.—Smith Inlet Sockeyes, 1950, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
3¼	1	1					2
4	2	—	—	—	1	—	3
4¼	6	—	—	1	—	—	7
4½	11	3	2	—	—	—	16
4¾	20	3	2	1	—	—	26
5	14	2	—	5	—	—	21
5¼	9	—	2	8	—	—	19
5½	3	1	1	15	—	—	20
5¾	1	1	8	17	—	—	27
6	2	—	7	26	—	—	35
6¼	1	—	7	26	—	—	34
6½	—	—	5	21	—	—	26
6¾	1	—	13	27	—	—	41
7	—	1	24	34	—	—	59
7¼	—	—	19	18	—	—	37
7½	—	—	12	21	—	—	33
7¾	—	—	15	11	—	—	26
8	—	—	15	4	—	—	19
8¼	—	—	7	1	—	—	8
8½	—	—	13	—	—	—	13
8¾	—	—	6	1	—	—	7
9	—	—	7	—	—	—	7
9¼	—	—	—	—	—	—	—
9½	—	—	2	—	—	—	2
9¾	—	—	1	—	—	—	1
10	—	—	—	—	—	—	—
10¼	—	—	—	—	—	—	—
10½	—	—	1	—	—	—	1
Totals	71	12	169	237	1	—	490
Average weights	4.9	5.0	7.4	6.6	4.0	—	6.5

Table XXII.—Smith Inlet Sockeyes, Average Lengths in Inches of Age-groups, 1945 to 1950

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945	—	—	22.2	22.0	25.1	24.4	—	—	—	—
1946	—	—	21.3	22.7	24.7	24.0	—	—	—	—
1947	—	—	23.2	23.4	25.2	24.3	—	—	—	—
1948	—	—	21.9	21.7	25.0	24.3	26.7	25.0	—	—
1949	25.4	23.5	21.4	21.7	24.6	24.3	—	25.5	—	—
1950	—	—	21.6	21.7	24.8	24.0	—	—	20.5	—

Table XXIII.—Smith Inlet Sockeyes, Average Weights in Pounds of Age-groups, 1945 to 1950

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945	—	—	4.9	4.7	7.1	6.5	—	—	—	—
1946	—	—	4.6	5.8	7.3	6.6	—	—	—	—
1947	—	—	5.7	5.5	6.9	6.0	—	—	—	—
1948	—	—	5.1	5.4	7.6	6.9	10.3	7.5	—	—
1949	7.9	6.1	5.0	5.1	7.2	6.7	—	7.3	—	—
1950	—	—	4.9	5.0	7.4	6.6	—	—	4.0	—

Table XXIV.—Smith Inlet Sockeyes, Percentages of Males and Females, 1945 to 1950

Year	4_1		4_2		5_2		6_2		5_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.		
1945	—	—	73	27	49	51	—	—	—	—	61	39
1946	—	—	76	24	37	63	—	—	—	—	41	59
1947	—	—	38	62	47	53	—	—	—	—	46	54
1948	—	—	79	21	42	58	11	89	—	—	43	57
1949	36	64	80	20	40	60	—	100	—	—	77	23
1950	—	—	86	14	42	58	—	—	100	—	49	51

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THE UNGAVA BAY PROBLEM

M. J. Dunbar*

In a civilized and increasingly complex world, native and primitive peoples become farther and farther removed from the apex of civilization, unless hey are assisted and educated to keep pace with, or to approach, that civiliza-on. This disparity in tradition and outlook becomes the more striking and he more serious where the two cultures touch one another, as when civilized an encroaches upon the economy of the native to such an extent that the riginal native economy has been totally disrupted and the native has become ore and more dependent on the civilized man.

In these circumstances the native can be easily and completely corrupted y the acceptance of unfamiliar moral standards which do not apply to his wn historic experience, and he can become so dependent on the white man's ade that he loses his original arts of hunting and travelling, and is then nable to look after himself if the economy of the white man deteriorates, r even fluctuates.

These ill effects have been demonstrated in many instances all over the orld. It follows that there is an obligation on the white man to protect the ative, or so to manage the affairs of the native that he survives—and this bligation rests on government rather than on the trading companies as such. n some parts, as in Greenland, the two have been the same; there was ntil recently, a government trading monopoly in Greenland. If they are not he same, as in northern Canada, it is still the concern and obligation of overnment to manage the affairs of the native peoples within the national oundaries, because the private trading company, which is commercially inter-sted, may not be able or willing to undertake the cost of the recuperation of he native economy, especially when the deterioration of that economy has one as far as in the Ungava Bay region of Canada. Government then reaps he reward of having at some earlier time taken the risk of entrusting the ffairs of the native to private interests.

There are two possible points of departure in a process of rebuilding the ative economy and morale: (1) to attempt to assimilate the native population mmediately into the activities of civilized man in the area; and (2) to attempt o put the native economy back on a footing as near as is reasonable to the riginal—at least to base it once more firmly on the real wealth of the native egion—and to graft in, gradually, the patterns of civilization in the process. oth these policies carry the assumption that the ultimate civilization of the ative population is inevitable, if not desirable.

The first alternative, although it seems to be popular at present, may be nworkable. A lengthy period of unearned support and of education is ecessary before the native people are ready to take part in civilized activities,

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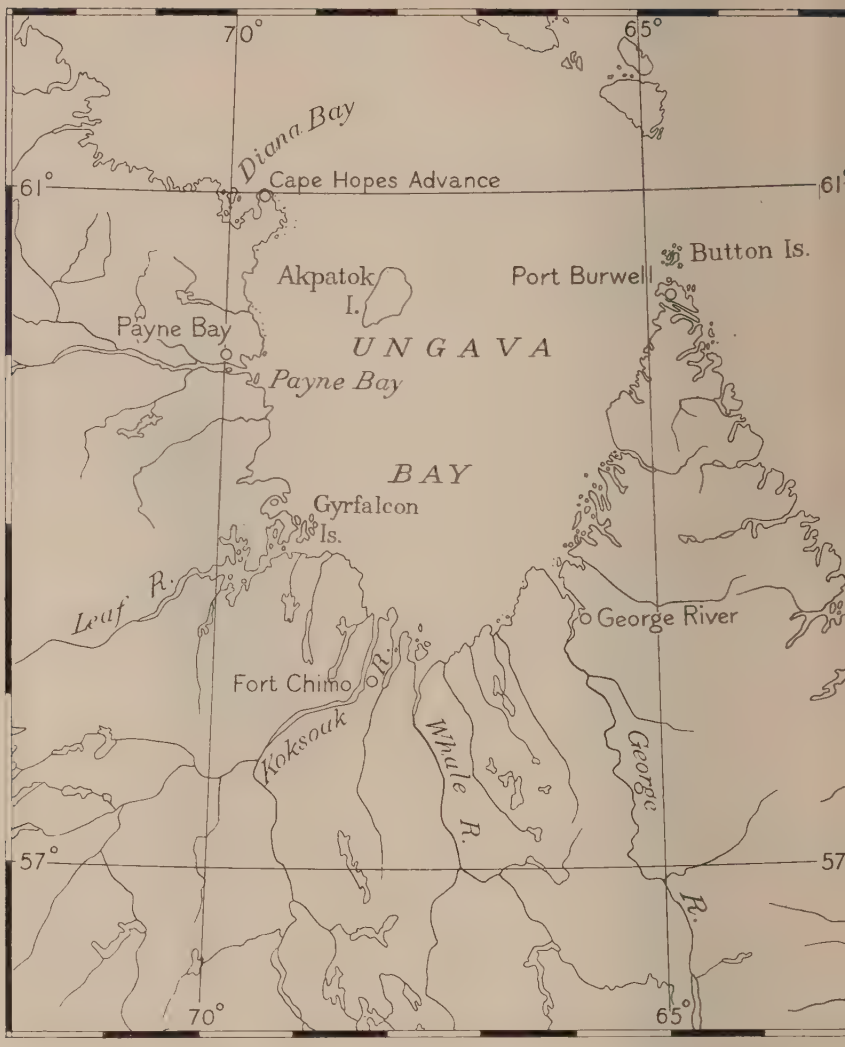


such as radio communication, air traffic, and mining. They can, of cours be used simply as cheap labour, in which case they are being frankly exploit and have no hope of ever being anything else. Assuming that the objecti is better than that, what is to happen in the period of education and apprentic ship, which may last for a whole generation? If they are allowed to contin to lose their original economy and means of livelihood, they become a dire charity load on the public exchequer, to the detriment of both the native a the exchequer.

The wiser course is the second, in fact it is probably the only course th is likely to succeed. In Greenland, where the process of introducing t native fully into civilized life is in mid-swing, the amalgamation of nati

Calanus in Calanus Harbour, Button Islands, August 1949.

raditional life and introduced civilized economy is the explicit policy of the Danish Administration. The principle has always been that the economy of Greenland should be based on the real wealth—the seals, the fish, and the fur —of the country, with assistance from mineral wealth when and where found. There was no deterioration of the native life comparable with what is happening now in Canada, although such a condition was threatened in the eighteenth century, leading to the formation of the Royal Greenland Trading Company n 1774, and the management of all trade in Greenland as a government nonopoly.

In Canada, at least in some parts of the Eastern Arctic, including Ungava Bay, there is a certain amount of back-tracking to be done before a ound condition is reached from which the process of civilized advancement an begin. It should be emphasized—for this is a point which, it seems, s not digested on first presentation—that the time-scale in this matter may e large. Significant changes in the economic habits of a human group annot be made in a few years, perhaps not in less time than a few generations. t has taken two hundred years to achieve the present stage of results in Greenland, and though the pace there has been deliberately kept down, those wo centuries of time must serve as a warning and a lesson to us in Canada who have begun, so recently, what the Danes began in Greenland so long ago.

Ungava Bay is a body of salt water, along the shores of which live less han one thousand Eskimo, who tend to concentrate at the trading posts of Payne Bay, Fort Chimo, and George River. From Port Burwell to Cape Hopes Advance is about 150 sea miles, and it is somewhat less than that from Akpatok Island to the mouth of the Koksoak River in the south. Trapping

Port Burwell, July 1949.

at Payne Bay is still good enough to warrant keeping the trading post open there, and Chimo serves as a trading post not only for the Eskimo, but for the small Indian population which formerly traded at Fort Mackenzie before that post was closed in 1948. It is understood that George River is to be closed in 1952, and the post at Leaf River was closed some years ago. There is no post now at Diana Bay, which lies just outside Ungava Bay, and the post at Port Burwell was closed in 1941.

Clearly the fur trade on the shores of Ungava Bay is not booming. The condition of the trade is of course reflected in the Eskimo, who are poor, and rely heavily upon family allowances and Government relief. They tend more and more to collect at the posts themselves, especially Chimo, and their diet contains too high a proportion of store-food—white flour, hard tack, lard, and tea. Their state of health is poor; on this point the writer has no details to publish, nor are any apparently available. The general initiative is correspondingly low.

The low state of enterprise and energy results, as would be expected, in reduced hunting and fishing activity. This, combined with the growing strength of the feeling that "the Government owes us a living", forms a depressing picture. One group of natives was willing, when it was suggested, to go up the Payne River after white whales which were known to be there, but expected as a matter of course that the necessary gasoline for fuel should be given them free. The gasoline was not forthcoming, and the whale hunt did not take place. Examples of this sort are fairly common. The reduced activity in hunting in turn reflects upon the nutrition of the natives, and so the process is circular, and spiralling downwards.

Fur is not the only resource that is in short supply. It must be said, in efence of the reluctance of the Eskimo to go hunting, that the rewards are ot overwhelming. Caribou are becoming increasingly scarce, by all accounts, nd according to report suffered a major, and unexplained, setback about 918, when the migrating herd which usually crossed the Koksoak River

Peterhead boats at Chimo, July 1947.

ach year, failed to appear. It has not appeared since. The sea mammals, lthough present, are not abundant in Ungava Bay, and moreover the season f good hunting is very short—about three weeks in June and July between he break-up of the ice and its disappearance from the bay. Almost all the ce has gone, in an average year at this point in the climatic cycle, by the iddle of July. The seal, especially the ringed seal (*Phoca hispida*), leave ith the ice; only a few bearded seal (squareflippers, *Erignathus barbatus*), nd fewer harp seal (*Phoca groenlandica*) and ringed seal, remain in the pen water for the rest of the summer. Even so, the number of seal sighted uring four summer seasons' field work in Ungava Bay is not so small as the ow hunting activity would lead one to suppose, and the families still energetic nough to go sealing can make considerable kills. One record, admittedly ery exceptional, is that of a camp in the southwest part of the bay in 194-, onsisting of two families in five tents, with two Peterhead boats and three

kayaks, which landed 79 ringed seals and 42 squareflippers in a period of about three weeks, in late June and July. Coming in to the mouth of the Koksoak River on 2 September 1950, the *Calanus* sighted about 12 harp seal, some 6 bearded seal, and a number of ringed seal, and groups of bearded seal were recorded in all four seasons both before and after the disappearance of the ice.

The winter hunting conditions on the ice are apparently very unsafe owing to the extremely large tidal range and the strong tidal currents; consequently there is little seal hunting in the winter.

It is not clear whether there has actually been a decline in the sea mammal population of Ungava Bay, or whether these waters have always, or for a long time, been comparatively poor in them. One native at Fort Chimo told the writer that "about 40 years ago" walrus were common at the Gyrfalcon Islands, in the southwest part of the bay, but it is doubtful whether great credence should be given this report without corroboration from other sources. Walrus now are common only at Akpatok Island, at certain times of year, where they are occasionally hunted by the natives of Payne Bay and the Cape Hopes Advance region, until the ice leaves the island in July. For most of the natives of Ungava Bay, walrus scarcely figure at all in the annual cycle.

It is conceivable that the recent warming of the marine (and atmospheric) climate of the Atlantic Subarctic, which has so strongly affected the west Greenland coast, has caused a reduction in the sea mammals of Ungava Bay, but it can scarcely be considered probable. It is true that the waters of Ungava Bay, at least the overlying layers, are subarctic—influenced, that is to say, by Atlantic water—and that such subarctic indicators as the Atlantic cod (*Gadus callarias*) and the Atlantic salmon (*Salmo salar*) are present in certain parts, but there is good evidence for the presence of both these forms at least as far back as the 1880's, so that recent hydrographic changes can hardly be postulated. Unfortunately, the first observations of salinity and temperature in Ungava Bay were made in 1947, and we have therefore nothing from which to construct the hydrographic history of the bay.

If any reduction in the sea mammal population has taken place, it is most probably the result of the use of the rifle by the Eskimo, and of the coarsening of the native hunting skill. From observation of Eskimo hunting in Ungava Bay during four seasons, the *Calanus* expeditions came to the conclusion that for every seal landed during the summer, three are lost owing to sinking, the seals having been killed by rifle fire from a distance, far out of harpoon range. Such a waste of a natural resource would never be tolerated among the fish and game circles in civilized communities, but it has been going on for years in the north, every summer. It has led to the natural conclusion that the seal population must be declining. It may be, but we have no proof of it.

Whatever the present status of the seal and walrus populations, it is certain that even were a return to the hunting manners of their forefathers possible, it would not solve the present economic problems of the Eskimo of Ungava Bay.

The establishment of an air base near Fort Chimo might have had as little effect upon the Eskimo as the Greenland bases have had upon the Greenlanders.

In the early years of the war the air bases in Greenland were declared out of bounds to the native population, and similarly the native settlements were off limits to military personnel, in fact to all personnel from the military establishments, with the result that the price structure carefully maintained by the administration over several generations did not suffer, and there was no deflection of the constructive efforts of the Greenlanders into the labour requirements of the airfields and weather stations, which for the native is a blind alley. At Chimo, however, and also at other northern airfields in Canada, there was no effort made to keep the natives off the base limits. They were welcomed, settled down in villages, and proceeded to forget a little more of the habits of independence. Employed as help in the mess, as unskilled labour, and a few as truck drivers, they gained a false sense of big-time importance, and the scorn or secret envy of their less evolved compatriots, according to the points of view of the latter. They became a little farther removed from an economy based on the real resources of their country, and the future holds nothing for them but the continuation of their present lot for as long as the work exists for them—or for as long as they wish it—and after that a return to the failing economy of the Ungava Bay Eskimo as a group, with still less mental equipment to deal with that problem than they had before.

It is of course a great saving to the white man engaged in building or maintaining a northern airfield to be able to employ local native labour at two dollars a day, rather than to be forced to import expensive white labour; and the glib official good intentions of those who wish immediately to "integrate the Eskimo with the march of civilization in the north" fit all too well into this saving of expense; but it is possible that such published intentions reflect a complete ignorance of the highly complex problems involved, or else an equally dangerous unwillingness to face them. The history of Indian affairs in the United States, with the object lessons of the dangers of walking into the slough of the easy way out, is before us; and the extraordinary complexity of the labyrinths through which it is now necessary to feel one's way back are well shown up by such studies as Dr. Laura Thompson's book 'Culture in Crisis' on the Hopi Indians, or Mr. John Collier's 'Indians of the Americas' on the American Indians in general. It is very important to realize that the feeding and clothing and shelter of the Eskimo is not by any means the whole of the question, and that the consequences to the native mentality of what amounts to a brutal dislocation of their traditional ways of life, and ways of thought, can cause irreparable damage. It appears that in all human affairs the mental damage wrought is the hardest to repair. To put the Eskimo problem in Ungava Bay in the picturesque terms used by the Brazilian natives employed in one of the Fawcett searches—their souls may never catch up with their bodies.

In 1947 the Fisheries Research Board undertook the study of the physical and biological oceanography of Ungava Bay, with a view not only to putting our knowledge of those waters (and of other Eastern Arctic seas) on the approximate level reached by other countries in other parts of the north, but

also to discovering, if possible, hitherto unused marine resources which could be developed by or for the Eskimo. Ungava Bay was found to be unsuitable for trawling or for normal commercial exploitation, but certain possibilities were brought to light at Port Burwell, and Burwell became fixed, in the mind of the present writer, as a possible key to the problem of Ungava Bay. Before dealing with this in any detail, it will be necessary to describe briefly the history of fishing activities of all kinds in this region. It is not a long history.

The Atlantic salmon reaches its northerly limit in Canada in the rivers of Ungava Bay, from the Koksoak eastward. The salmon start to run between late July and the third week in August. The run is variable in extent, and therefore unreliable as a source of food for man or dogs. Nevertheless the salmon is of some importance economically to the Eskimo of Ungava Bay, and the unreliability of the upstream run is therefore a matter of considerable concern to them. The fish are taken in gill nets. The present annual catch on the Koksoak River probably varies between about 10 and 40 300-lb. barrels. The catch in 1947 was estimated at about 35 barrels, in 1948 less than 12 barrels. The George River catch was approximately the same in 1947 as on the Koksoak, but in 1948 less than 5 barrels were obtained.

It is possible that the salmon fishery was damaged by commercial fishing which began in 1881 (on the Koksoak; 1884 on the George and Whale rivers), and continued until the early 1930's. Both the total catch and the average weight began to decline as soon as the fishery opened. About 40 tons of fish were frozen for shipment in 1881, average weight 19 lbs.; 24 tons in 1882, average weight 16 lbs.; 38 tons in 1883, average weight 14.5 lbs., and less than 40 tons in 1884, average weight 14.7 lbs. In 1899 A. P. Low reported that the salmon fishery had steadily declined and that in 1897 it had been an almost complete failure. The present status of the salmon population is uncertain.

The arctic char (*Salvelinus alpinus*) occurs in all suitable rivers in the area; in the southern part it is replaced in some of the smaller streams by the speckled trout. During the upstream migration it is caught in gill nets and with long-poled gaffs, and in much smaller numbers it is taken also in the winter, in lakes. It does not appear to support so important a fishery as does the salmon, no doubt because the latter is the larger and therefore the more valuable fish to the Eskimo. As is usually the case with the arctic char, it could be subjected to considerably greater fishing by the native population, if the activity were spread over the many streams which are now hardly touched at all. Intensive fishing on one river, however, would probably do serious harm.

There is a certain amount of winter fishing on the lakes, with gill nets set beneath the ice, for lake trout and whitefish.

It will be observed that there is no salt water fishing in the above account. Apart from the netting of salmon and char in tidal stretches of rivers, the jigging of a few sculpin, and the catching of the occasional codfish (at Burwell), there is no sea fishing activity in the bay. While it is possible that both salmon and char fishing, particularly the latter, could be developed by

the Eskimo, these two resources could not provide the volume of native or "country" food necessary to restore the economy to health. Salt water fishing at Burwell, however, might save the situation.

It is significant that Burwell, the least attractive of the Ungava Bay settlements from the point of view of the fur trader, should appear as the richest of them all from the point of view of the old-style Eskimo. There is no doubt that it is. Burwell is on the route of one of the groups of harp seal on their fall migration to Newfoundland, in October and November, and this alone assures the few Eskimo left there of enough seal for almost the whole year. Burwell also lies close to the Button Islands, which can usually be relied upon to provide good seal hunting throughout the open season (the islands cannot normally be reached in the winter). Ringed seal, harbour seal (*Phoca vitulina*), harp seal, and squareflippers are all taken in summer at the Button Islands by the Burwell natives, although the shortage of good boats makes the visits somewhat rare. Polar bear are occasionally shot there. The waters in the immediate vicinity of Burwell itself also appear to be richer in seals, especially bearded seals, than the remainder of Ungava Bay.

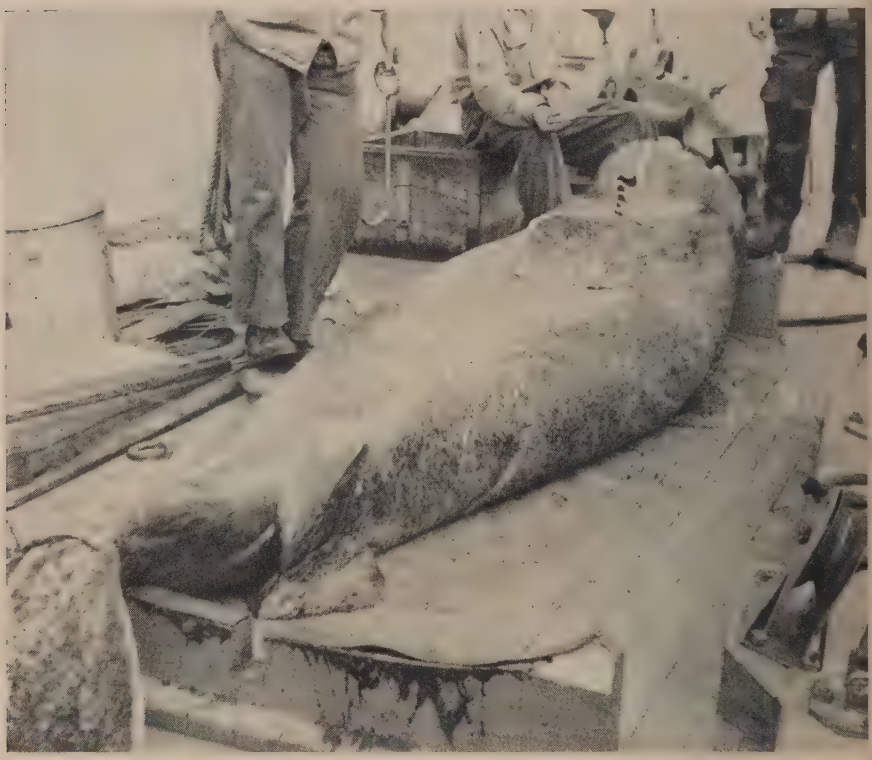
It is not surprising that the few Eskimo who did not leave Burwell in 1941 when the post was abandoned (there are now about twenty of them) should be the best situated in the bay. The surprising and depressing thing is that so few stayed, that the majority preferred to follow the trade-store to George River or Chimo.

Burwell stands out from the other points in the Ungava Bay coast in one other respect—it is the only place where a marine fishery could be developed. Atlantic cod (*Gadus callarias*) spend some ten weeks at least in the Burwell area, from the latter part of July to the end of September approximately, and can be caught by hand-line at the rate of about 20 fish per man-hour, or a little higher. The fish are fairly small, up to about 75 centimetres, but they are good eating. The Greenland shark (*Sommiosus microcephalus*) is common, and could also be used, once the Eskimo gets over his aversion to the shark. Sharks are a nuisance to the seal hunters, who seem somewhat scared of them, and they have never learnt, as the Greenlanders have, the value of the liver, or to use the dried flesh for dog-food; and they are quite unaware that there exists anywhere a market for the skin.

Marine fisheries, and the possibility of marine fisheries, are rare in the Arctic. They belong to the Subarctic and to zones farther south, and it is worth observing that the Eskimo, who have arrived in Greenland and the Labrador by arctic routes, have not developed marine fisheries to any significant degree by themselves, but only with the initiative and help of white men. Where marine fisheries have been developed they have proved of vital importance to the native, especially in west Greenland, where the cod fishery is now by far the biggest single industry. The Burwell area of Ungava Bay, it should be emphasized again, is subarctic, so far as the sea is concerned.

In Ungava Bay, it is clear that the one group of Eskimo who do not need help, by the development of fisheries or anything else, is the little Burwell group, and yet it is there that a possible solution of the Ungava Bay

problem as a whole is to be found, in cod fishing and shark fishing. The general objective of a "Royal Commission on Ungava Bay" might be the turning of the Eskimo's attention to Port Burwell, and the stimulation of a native fishery there which would provide salted, frozen, or possibly dried fish for distribution to other points along the coast, for human and canine consumption. (The Burwell climate is not well-suited to drying fish.) This development would involve the summer migration of some of the natives from



Greenland shark (12-foot) on deck of *Calanus*, August 1949.

Chimo, Payne Bay, and George River, to Burwell; it would at the same time bring them to better sealing waters, and they might be able to remain, after the fishing, for part or all of the period of migration of the harp seal.

The bare bones of this scheme are easy to draw. There are practical problems involved, none of them, I believe, insoluble. For the proper operation of such a fishery, there will be a need for: (1) a small processing station at Burwell; (2) more boats; (3) the education of the Eskimo, and (4) a system of internal trade in Ungava Bay which will both distribute the fish economically and fit it into the established summer activities, such as salmon fishing and sealing. It will require, at first, a capital outlay on a small scale and the system will probably not pay for itself in the first few years. Almost certainly it

must be administered by government, but it would be wise to do it rather more economically than many Government enterprises in the north.

An experimental fishery station was in fact set up in 1950, by the Northern Administration of the Department of Resources and Development, and the few Eskimo at Burwell were induced to catch codfish with hand-lines, for their own use. Some 6,000 fish were salted away. The enterprise was strictly experimental, intended to demonstrate the scale upon which such a fishery could be maintained. The fact that the salt fish were not immediately con-

Peterhead boats at Payne Bay, July 1947.

sumed by the Eskimo is immaterial—it has already been pointed out that the Burwell natives themselves do not need the fishery.

Apart from one Peterhead boat which the Hudson's Bay Company moved from Lake Harbour to Port Burwell in 1951, in connection with a possible fishery there, there has been no new boat brought into Ungava Bay for many years; and the present state of the fur trade does not suggest that the purchasing power of the native will be able to bring them, in the foreseeable future. It is understood that arrangements are being made at present for the building of whaleboats at certain northern trading posts, including the Ungava Bay region, and this may considerably ease the present shortage. For the distribution of Burwell fish to other parts of the bay, however, at least one larger vessel will be required, perhaps a 50-foot boat with good cargo space, which could be beached at Fort Chimo each winter. Such a vessel could also transport some of the Eskimo engaged in the Burwell fishing. Small dories are best for the actual fishing, which would be largely by hand-line—long-line does not appear

to be a useful method at Burwell—but native-owned whaleboats and Peterhead boats could also be used. These latter boats at present have gasoline engines. With gasoline at a dollar a gallon, it would probably be better to change over at some time to diesel engines, and to induce the Eskimo to re-learn some of their old sea-going habits and use sail alone whenever possible. There is seldom any prolonged absence of wind in Ungava Bay.

The problem of the education of the Eskimo is far wider than the present matter of the development of a fishery at Burwell, but the fishery is one of the kind of things for which they have to be educated. Only two points need be made here; first, that we are disgracefully late in introducing adequate schools in the north, and second, that much of the ordinary grade school curriculum is not appropriate to Eskimo purposes. The Eskimo needs to know precisely what his position is in the modern world, and what the real foundations of his present economy are. For this he needs to learn English, a little mathematics, some practical mechanical and electrical engineering, and some biology—not the kind that demonstrates that under certain circumstances a bean will germinate, which he knows already, but the kind that deals with the balance of natural populations, including his own. Whether he becomes a little Protestant or a little Catholic is a secondary consideration. If the curriculum is specially designed for the Eskimo, and if the teachers themselves know what the present issues are in the north, the schools will be a great success. If our own educational system is simply moved north, and if the teachers imagine that teaching the Eskimo is in no way different from teaching anyone else, the schools might as well not be built.

The system of internal trade best suited to the fitting of a marine fishery into the Ungava Bay economy is essentially an *ad hoc* problem; it can be adapted to the immediate situation. Certain things can be foreseen, however. Those who leave Chimo or George River to fish for cod will miss the salmon fishing. This should not reduce the salmon take significantly, if at all, since the number of nets operated can be held constant, but the salmon fishers may produce a surplus over and above their own needs. The cod fishermen certainly will produce a surplus, especially the native Burwell population who may have no need for the fish at all. Some system of barter, therefore, will be necessary. The seal take at Burwell will be increased, much of which will be taken back to Chimo or George River; some could be traded for spruce logs from Chimo, just as sealskins from Payne Bay are at present sometimes traded for firewood from Chimo. Depending on the extent to which the Government or trading company are involved, it may be best to buy some of the cod with cash, and to open a trade-store at Burwell. The cod so purchased would then be taken to other coastal points in the fall. Certain of the products of such a fishery might be saleable in outside markets, such as shark- and cod-liver oil, and shark leather. Possibly a cooperative system could be developed.

Many old hands in the north may not like these ideas. Eskimo, they may say, will not fish for cod; they will not eat salt fish; they will not touch shark, and so on; to all of which one obvious counter is that the native

population of Greenland is engaged in shark and cod fisheries, and the salt can be leached out of the fish. It could also be pointed out that there must have been a time when the trapping of foxes seemed just as foolish a novelty to the Eskimo hunters as cod fishing may seem today, and that their employment at air bases must come less naturally to them than going to Burwell to fish. Moreover, there are other new things on the way. Mining, for instance, may open up on Ungava Bay any year, on a large scale. If Eskimo can be employed in mining operations, they can also go fishing for cod, and moreover the mining companies (and the personnel at air bases or weather stations) would provide an immediate market for some of the fish.

The argument has also been raised that there is not time for such a development as has been suggested here, that the problem of bringing the Eskimo into the march of civilization is immediate. The Eskimo, it could be maintained, is highly adaptable, and would come to no harm by such a rapid transition from hunter and trapper to miner or radio technician, and he could learn the necessary techniques very quickly.

A third, and not very admirable point of view might be that it is not worth all this trouble; less than 1,000 people are involved in Ungava Bay, and besides they have little political importance. Such an attitude does exist. It can be firmly rejected, but it cannot be ignored.

There is, in fact, plenty of time to follow the general policy advocated in the early part of this article. If at the same time it is possible to train Eskimo quickly to become skilled as well as unskilled labour, well and good; at least we must have the proper schools. And in general, the two cardinal rules of policy in handling the Eskimo problem should surely be: (1) no charity (beyond the usual matters of the aged and the disabled), and (2) use the local resources to the utmost, consistent with their conservation.

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Precision Semimicro Hydrogenation Apparatus

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WITH few exceptions (*4*, *5*), all the laboratory hydrogenation apparatus described in the literature derive from the simple assical device shown in Figure 1. This is composed of a vessel, , or hydrogenation cell, a graduated buret, *B*, and a leveling rrangement including a leveling bulb, *L*. In the cell is shaken a ixture of unsaturated compound, catalyst, and a solvent when quired; the hydrogen contained in the apparatus is absorbed as e reaction progresses. This system allows a measurement of the bsorbed hydrogen to be made and therefore can be used for de- rmination of unsaturation values (absorption at the completion f the reaction) and of hydrogenation rates.

With this type of apparatus, hydrogenation values (*2*) are ob- ained with a precision of ±3%, provided the proper technique is used. If accuracy is not the main objective, this is the ideal equipment, being simple to construct and easy to handle.

Many modifications have been proposed; some lead to somewhat better results but in no case is a precision better than 1% to be expected. The sources of error are many and no apparatus proposed so far eliminates them all satisfactorily.

When, instead of hydrogenation values, hydrogenation rates are required, the difficulties involved are greatly magnified. This type of study not only calls for a much higher precision but also numerous timed readings.

The equipment shown on Figure 1 is unsuited for this type of work. The essential drawback is the practical impossibility of making frequent and precise readings when the pressure has to be

continuously adjusted by manual control. Even assuming this to be feasible, undesirable interferences due to other sources of errors inherent to the system come into play. Most of these stem from the fact that the system is not well defined thermodynamically. Small variations of temperature and pressure are impossible to avoid. They exert a distorting effect which precludes the accurate measurement of the volumes absorbed (*8*).

Another less obvious but very important source of errors is due to agitation. It is not immediately realized that the system under observation is limited to the liquid phase; the hydrogen reaching the catalyst does not come directly from the gas phase but is supplied by the hydrogen dissolved in the liquid medium. Thus its concentration in this liquid is the thermodynamic factor affecting the reaction rate. Should this concentration vary in an uncontrollable manner, the system would no longer be defined. Unless a large gas-liquid interface allows the hydrogen from the gas phase to diffuse and replace quantitatively the dissolved hydrogen used up by the reaction, fluctuations in hydrogen concentration will occur with subsequent distortion of the rate curve.

Agitation efficiency and control are thus very desirable features.

The apparatus described fills these important requirements, along with several others of lesser importance. Essentially, it is derived from the simple device shown in Figure 1. Structural simplicity has been sacrificed to a certain extent, but the handling of the apparatus is still very simple. There is a considerable gain in sturdiness, reliability, and precision.

Hydrogenation values can be obtained with an accuracy better than ±0.3% for a single determination, using amounts of material that will absorb as little as 1 cc. or as much as 50 cc. of hydrogen. (With the 50-cc. buret the volume absorbed should be at least 10 cc.) True hydrogenation curves are obtained and precise readings can be made as frequently as one every 15 seconds.

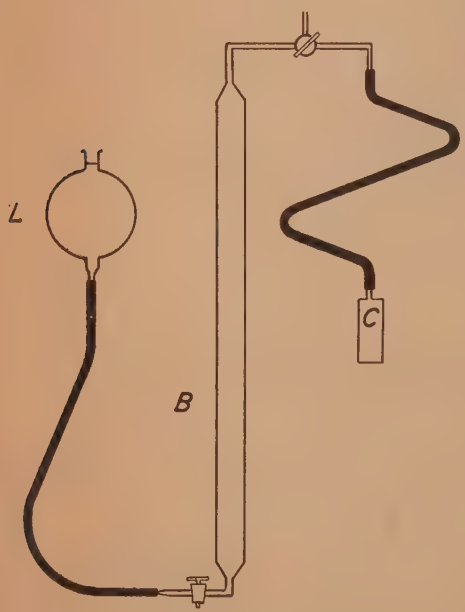

Figure 1. Classical Hydrogenation Apparatus

This result was obtained by simultaneously incorporating the following features:

Maintenance of preset pressure within 0.03 mm. of mercury.
Maintenance of working temperature within 0.01° C.
Automatic leveling.
Use of organic liquid of low density instead of mercury as leveling fluid.

No apparatus described in the literature allowed the determination of hydrogenation values with a precision better than 1%, and the precise study of catalytic hydrogenation rates under fully isobaric and thermostatic conditions, with semimicro and micro quantities. The new apparatus allows such studies to be made. Its features overcome the drawbacks of hydrogenation apparatus in general, and allow good control of the conditions used and easy manipulation. The precision is about 0.3% for one determination of the unsaturation value involving a few milligrams of unsaturated compound and the rate curves observed are reliable. This apparatus can be used for obvious analytical purposes as well as for the study of catalyst activity, catalyst selectivity, and behavior of unsaturated compounds under hydrogenation, and preparative work on a semimicro scale.

Saturation of the leveling fluid by hydrogen and exclusion o foreign gases.
Efficient and controlled agitation.
All-glass, leakproof, rigid construction.

DESCRIPTION OF APPARATUS

The main parts of the apparatus are: the hydrogenation cell, (Figure 2), the buret, *B*, the leveling tube, *L*, the leveling liqui reservoir, *R*, the manostat, *M*, the needle valve, *N*, and stopcock *P*, *Q*, and *X*.

Appropriate manipulation of these stopcocks (straight-bor three-way) allows the following connections to be made, excludin all others: (1) vacuum line *V* to cell, (2) hydrogen supply line t cell, (3) cell to buret, (4) buret to hydrogen supply line *H*, an (5) hydrogen supply line to bubbler tube *Z'* (in reservoir *R*).

Buret *B* is connected to the leveling tube, *L*, by stopcock (Figure 3). The latter also allows liquid to be drawn either fro the buret or from the leveling tube. Reservoir *R* contains a sup ply of leveling fluid maintained saturated in hydrogen (bubble tube *Z'*) and free of other gases.

The reservoir is connected to the base of the buret by tube Opening of needle valve *N* will allow leveling fluid to flow in th buret, leveling tube, or both, depending on the position of stop cock *E*.

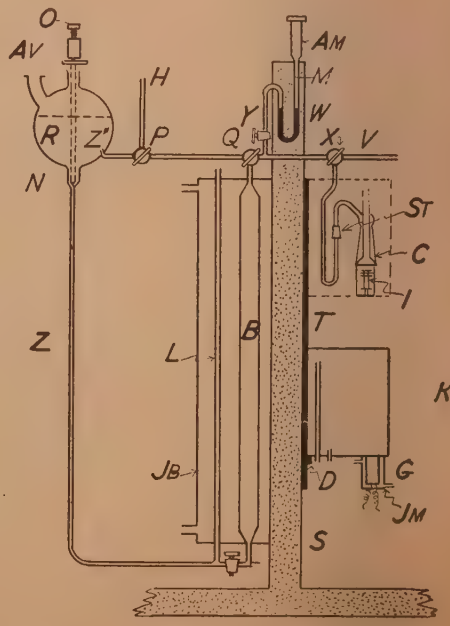

Figure 2. Diagram of Improved Apparatus

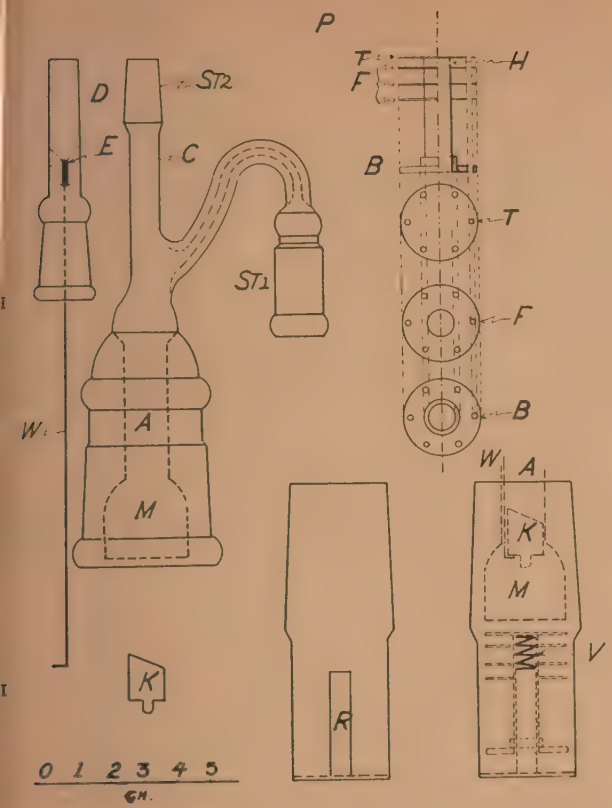

Figure 3. Apparatus

The manostat, *M*, can be connected to the cell-buret system by pening stopcock *Y*.

A stand, *S*, supports the apparatus.

CONSTANT-TEMPERATURE SYSTEM

A water bath (28 liters) kept at a temperature constant within 01° supplies thermostated water to the system (small centrifugal mp).

The water flows first into the jacket, *Jb*, surrounding the buret nd leveling tube, then to tank *K;* from *K* it flows back to the ath.

Tank *K* is glass-sided; it can be moved up and down, sliding on vertical track screwed on stand *S*. In its lower position, tank *K* sts on knob *D*. The cell is then fully accessible and can be sily disconnected from or adapted to the rest of the apparatus. standard joint, *St*, is the connecting part. The cell is the only art of the apparatus ever removed.

When tank *K* is made to slide up the track *T*, it occupies the pper position (dotted line). The cell is then surrounded by con- ant-temperature water.

By means of a branch tube, the water is also circulated through he jacket, *Jm*, housing electromagnet *G*.

AGITATION

Agitation is effected by plunger-stirrer *I* actuated by magnet *G*. his magnet is screwed in the base of tank *K* in such a position at, when the tank occupies its upper position, the flat base of the ll rests squarely and centrally on *G*.

The movement of the stirrer is not the conventional rotation; is animated by rapid vertical oscillations. (A conventional ro- ary magnetic stirrer could be used if hydrogenation values were he only requirement. Kinetic studies, however, require a more licient stirrer.) The effect is obtained by interrupting the ex- ting current several times a second. When the current is passing rough the coil, the stirrer, resting on a small spring, is pulled own; when the current is interrupted, the spring restores its rtial position. The spring is made of six turns of gage 0.016-inch allace Barnes, Hamilton, Ontario, stainless steel spring wire. ength is 6 mm. relaxed. As a consequence of the particular ape of the stirrer, a very large gas-liquid interface due to numerous small bubbles is created and maintained throughout the liquid.

The construction of the plunger is shown in Figure 3, *B*. The body is made of Carpenter stainless steel No. 5. The base, *B*, is made of soft steel subsequently chromium plated. The thickness of the fins, *F*, is 0.2 mm.; the top fin, *T*, is 0.5 mm. thick; the thickness of base *B* is 1.2 mm. All the fins and the base are perforated by six holes of 2-mm. diameter. Between *T* and the next fin, a 2-mm. hole, *H*, is bored through the shaft on both sides. The weight of the stirrer is 16 grams.

The agitation intensity can be varied by adjusting the rate of pulsation of the current, the amplitude of the movement, or both.

Pulsations varying from 300 to 500 per minute are obtained by a system of cam and contacts operated by a synchromotor. The current is 12 volts direct current supplied by a rectifier (5 amperes). Car batteries can be used.

This system allows a very steady state of agitation to be maintained.

PRESSURE MAINTENANCE AND AUTOMATIC LEVELING (FIGURE 2)

Thermostat *M* is a differential manometer half-filled with mercury. It is branched on the connection between the cell and the buret. A slight lowering of pressure (such as caused by hydrogen absorption) causes the level in one branch to lower. This breaks a contact, *W;* breaking this contact operates magnet *Av* (through the action of a sensitive electronic relay) which lifts the glass needle valve, *N*. This causes leveling fluid to flow from reservoir *R* into the buret until the preset pressure is re-established. The position of contact *W* is adjustable by the rotation of knob *Am*. The operating pressure, which is the atmospheric pressure of the moment, is maintained by this sturdy arrangement within 0.03 mm. of mercury.

Manipulation of knob *O* allows the adjustment of the needle valve opening gap and thereby the control of the compensating impulses in amplitude.

This automatic setting of the level leaves the operator's attention entirely free, a condition prerequisite to precise observations. As leveling fluid, it is desirable to use the same solvent as in the cell.

THE CELL

The hydrogenation cell (Figure 3, I) is made of a No. 34/45 standard joint. The lower section, made of the inner part of the joint, has a flat base. A certain length of glass rod, *R*, is fused by one end in the center of the base, perpendicularly to its plane. This rod acts as guide for the plunger, *P* (Figure 3, II and IV). The small stainless steel spring, *V*, is located in the plunger shaft and sits on top of the glass rod, *R;* when magnet *G* is not energized, *P* occupies the position shown in Figure 3, IV.

The top section of the cell (Figure 3, I) is made of the outer part of the No. 34/45 standard joint. It comprises a central tube, *A*, ending in a hemispherical shield, *M*, opening downward. The external diameter of the largest section of the shield is only 0.5 mm. smaller than the internal diameter of the bottom part of the cell. The purpose of the shield is to catch all the droplets projected from the liquid during the operation and to return them to the solution.

The other end of tube *A* is sealed to a tube *C* bearing the inner part of a No. 12/30 standard joint, St_2. The outer part of this joint is at the end of tube *D*. The latter bears, sealed inside, a small length of capillary tubing, *E*. A stainless steel wire, *W* (1 mm. thick), is sealed by one end in this capillary tube (de Khotinsky cement). The other end is bent at right angles.

A small glass capsule (Figure 3, III), *K* (containing the sample to hydrogenate), can be inserted in tube *A* and supported by the bent end of the wire (Figure 3, IV). A 90° rotation of *D* will cause the release of the capsule when this is desired.

The side tube, *T*, is fitted with the outer part of a No. 12/30 standard joint, St_1, which allows the cell to be connected to the buret assembly.

MICRO AND SEMIMICRO EQUIPMENT

A precision borosilicate glass (1-, 2-, or 5-cc.) microburet body together with a leveling tube 12 mm. in diameter constitutes the micro combination.

The semimicro combination comprises a 50- or 25-cc. precision, borosilicate glass buret body and a leveling tube 6 mm. in diameter.

Both can be incorporated in the same apparatus, as shown on Figure 4. However, by using special stopcocks (Figure 4, *C*), the system can be reduced to the two burets only, one micro and one 50 cc. or 25 cc. Either is used as the leveling tube when the other is used as buret (Figure 4, *B*).

HYDROGEN SUPPLY

Electrolytic hydrogen (cylinder) is passed through a purifying train consisting of: reducing valve, mercury safety valve, porous plate gas-washing bottle containing an alkaline solution of sodium plumbite (7), platinized asbestos oven (300° to 350°), and porous plate gas-washing bottle containing the same solvent as used in apparatus (leveling liquid and solvent in the cell).

The train is maintained under a slight pressure when not in use. The apparatus is ready to operate as soon as the oven has reached 300°.

HYDROGENATION TECHNIQUE

A certain amount of catalyst is placed in the bottom of the cell For the determination of hydrogenation values, this amount need not be known. The spring is inserted inside the stirrer shaft and the stirrer is slipped on the guide rod. A standard amount of solvent is added, such that, when the stirrer is pulled down, about 1 mm. of liquid covers the top. The capsule containing the weighed sample is inserted in the central tube of the top part of the cell and secured in position by rotating the bent end of the wire inward.

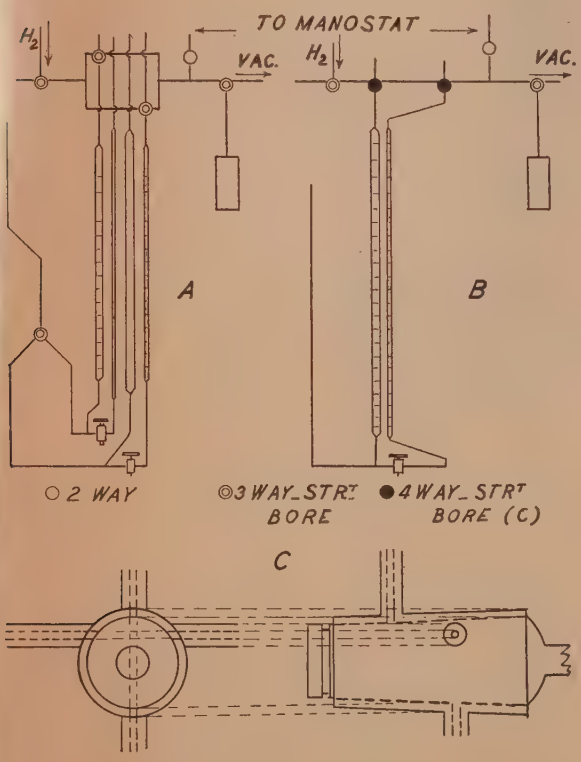

Figure 4. Microapparatus

Bottom and top parts of the cell are brought together (vaseline) and the cell is connected to the apparatus.

Tank *K* is lifted and locked in its upper position; the constant-temperature water flow is directed through the apparatus.

The buret is filled with hydrogen by opening stopcock *E* after the buret has been connected to the hydrogen supply; hydrogen thus replaces the liquid drained from the buret.

Filling the cell with hydrogen is accomplished by connecting the cell first to the vacuum line (water pump), then to the hydrogen supply line. This is repeated several times; after ea filling, the stirrer is operated for a few seconds in order to libera foreign gases from the liquid. After the final filling, stopcocks and *X* are adjusted to connect the cell to the buret. By mane vering stopcock *E*, the levels are equalized.

The manostat is then connected to the system, and the aut matic leveling mechanism and the stirrer are switched on. T apparatus is left operating until no more hydrogen is absorbe the medium (catalyst and solvent) is then fully reduced a saturated with hydrogen. After a final careful adjustment, t level in the buret is read; subsequent release of the sample caus hydrogen absorption to be resumed.

When the hydrogen value is the only requirement, the level read when absorption ceases.

Should a rate curve be required, readings are made at tim intervals. A convenient technique to ensure on-time readings to use a minute-sweep electric clock arranged so as to give audible signal before (warning) and at the preset time for t reading.

Table I. Hydrogenation Values for Sample of Fumar Acid with Platinum Black (Reduced PtO_2) as Catalyst

1.736	1.735	1.740
1.734	1.736	1.740
1.737	1.736	1.737
1.735	1.737	1.736
1.738	1.739	1.735
1.735	1.740	1.740
1.738	1.742	1.736
1.739	1.734	1.734
1.739	1.736	1.735
1.737	1.735	1.733
Av.	1.7368	
Theoretical	1.7374	
Largest deviation from average		+0.005 −0.004

EXAMPLES

Hydrogenation Values. Table I gives a series of values dete mined by using variable amounts of fumaric acid (British Dr House-C.C.) in the presence of Adams catalyst (PtO_2) (Ethyl alcohol (95%) was used as a solvent. The volumes a sorbed were from 1.05 to 4.5 cc. (microburet) and from 12.1 50 cc.

Table II. Hydrogenation Rate of Methyl Oleate wit Raney Nickel

(Me oleate W5 − 1. Run 9-266. C_o = 16.80)

T, Time	*C*, Concn.	ln C_o/C	$k = 1/T \ln C_o/C$
4	10.66	0.455	0.1137
5	9.49	0.571	0.1142
6	8.45	0.687	0.1145
7	7.49	0.808	0.1154
8	6.65	0.926	0.1158
9	5.93	1.041	0.1157
10	5.25	1.163	0.1163
11	4.66	1.282	0.1166
12	4.15	1.398	0.1165
13	3.71	1.510	0.1162
14	3.34	1.610	0.1150
18	2.15	2.056	0.1142
22	1.34	2.528	0.1148
24	1.04	2.782	0.1159

The expression giving the theoretical hydrogenation value i

$$\text{H.V.} = \frac{n\ 201.6}{M}$$

where *n* is the number of double bonds and *M* is the molecul weight.

In this particular case, the theoretical value is 1.7374. In t series of experimental values, recorded in Table I, the average 1.7368. The largest absolute deviation from the average is 0.0 thus less than 0.3%.

The expression used in calculating experimental hydrogenation values is:

$$\text{H.V.} = 100 \times \frac{V}{10^{-3}W} \frac{p - p_s}{T} \times \frac{273.1 \times 0.0898 \times 10^{-3}}{760} = 3.227 \frac{V(p - p_s)}{WT}$$

where

V = volume absorbed, cc.
W = weight of sample, mg.
T = absolute temperature
p = pressure
p_s = partial presssure of solvent at $T°$
0.0898×10^{-3} = specific gravity of hydrogen NTP

Hydrogenation Rate Curves. Pure methyl oleate (*6*) was hydrogenated with W5 Raney nickel as catalyst (*3*) and 95% ethyl alcohol as solvent.

Table II shows, in column one, the time of the readings (T minutes) and in column two, the concentration, C, of methyl oleate present at the time of the reading. This concentration is expressed by the volume of hydrogen still to be absorbed. In column three are indicated the values of the ratio $\ln C_o/C$ where C_o is the initial concentration—i.e., the volume absorbed at the completion of the reaction. The value of $K = 1/T \ln C_o/C$, shown in column four is comprised within very narrow limits, indicating that the reaction is of the first order in respect to the concentration of methyl oleate. The rate curve is this case is a straight line (rate *vs.* C) passing through the origin (slope = K).

The remarkable consistency of the K value is indicative of the precision attainable.

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Partition Chromatography of Aliphatic Acids

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At the time the study was undertaken, no method existed for effectively separating monocarboxylic acids from C_2 to C_{12} and dicarboxylic acids from C_4 to C_{10}. Results described in the literature for monocarboxylic acids were difficult to reproduce, some of the methods were laborious, and factors affecting the resolving power of the column were not well defined. A new multicolumn technique allows the separation of monocarboxylic acids from C_2 to C_{12}, and with only a modification of the column mixture composition, dicarboxylic acids from C_4 to C_{10}. Recoveries are often better than 95%. An apparatus well adapted to partition chromatography in general, preparation of column mixtures, method of packing, and method for determining acid band boundaries and for microscale preparation of derivatives are described. The method is more rapid and reliable than previous methods. Natural products, fermentation products, and oxidation products present a wide field of application.

NO METHOD existed for effecting the separation of dicarboxylic acids from C_4 to C_{10} by chromatography, and none of the methods described in the literature for separating monocarboxylic acids from C_2 to C_{10} were entirely satisfactory. The most effective method (*8*, *9*) did not allow a complete separation of C_9 and C_{10}. In general, results were difficult to reproduce, perhaps because the techniques were too vaguely described. Consequently, the investigation described in this paper was undertaken.

MONOCARBOXYLIC ACIDS FROM C_2 TO C_{12}

Mixtures covering the whole range of the steam-distillable fatty acids cannot be resolved completely by any single method based on partition chromatography. Research in this direction is very active; the review published in 1949 by Cassidy and Nesterov (*2*) reveals a general interest in a procedure applicable to the largest possible number of these acids. Recently, Fairbairn and Harpur (*3*, *4*) have described the separation of all the acids from C_2 to C_8.

The method described below has extended this range to C_{12}.

OUTLINE OF METHOD

Using a modification of a procedure described by Ramsey and Patterson (*8*, *9*) it was possible to prepare a column, about 4 cm. long, from which all the acids from C_7 to C_{12} could be separated and eluted in distinct bands. The elution of the lower acids from this column is, however, extremely slow. Although successive changes in the mobile phase composition will allow the elution of the lower acids to take place, it was found more practical to make use of the following observation: A much shorter column, made of the same mixture and treated with the same solvent, is very efficient in separating the acids below C_7; at the same time, a positive indication of the number and identity of the higher acids is obtained. Consequently, the proposed procedure is to chromatograph the unknown on a short column (C_2 to C_7) and to repeat the operation, using the same solvent and technique, on a longer column (C_7 to C_{12}) made up from the same mixture. The short and long columns are referred to below as column I and column II, respectively.

Detecting Band Boundaries. The next problem consisted in detecting band boundaries. They correspond to eluate fractions of lowest acidity immediately followed by fractions of much higher acid content.

The general procedure consists in collecting fractions of known volume and titrating them separately in order to detect the transition points. The limit of accuracy thus obtainable is clearly dependent upon the size and, therefore, the number of the fractions collected. With numerous acids eluted in relatively close succession, one may have to deal with as many as a hundred fractions. The collecting operation is impractical when the receiver has to be changed manually. A suitable automatic fraction collector is conceivable, but would still leave unsolved the problem presented by a lengthy titration operation to be conducted in a carbon dioxide–free atmosphere.

Several attempts have been made to avoid the cumbersome step-by-step analysis of the eluate. Simplified procedures have been proposed relying either on threshold values or on visual indication. Unfortunately, none is satisfactory in the present case. Threshold values are too dependent on sample composition to constitute reliable guides; and the colored bands obtained by adding an indicator to the column material (*8*, *9*) fade out toward the base of the column when the higher acids ($> C_9$) are involved, especially in small quantities. Finally, the procedure for detecting the change in acidity corresponding to the surge of a new band (*7*) is insensitive when weak acids ($> C_8$) are concerned.

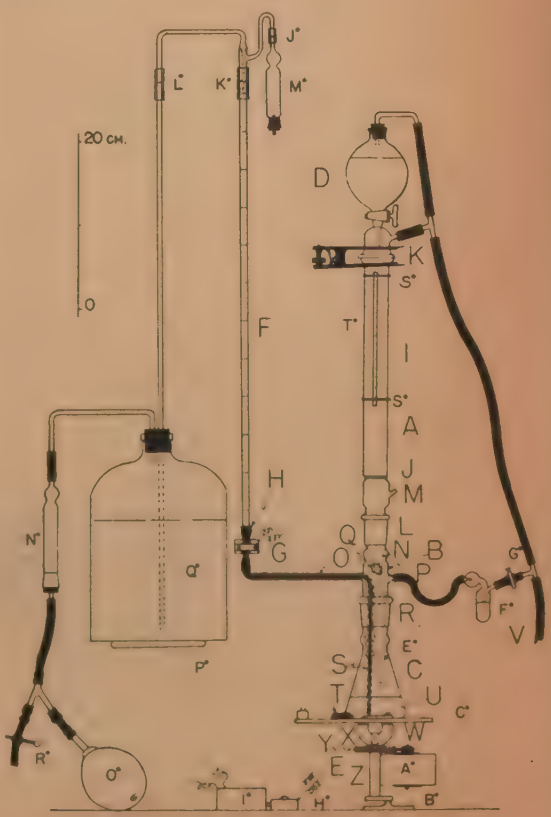

Figure 1. Diagram of Apparatus

In the present method, the difficulty was overcome by continuously collecting and titrating the eluate in a receiver that is never changed. The proposed procedure consists in alternately adding a certain amount of an alkaline solution to the continuously stirred contents of this receiver and allowing the eluate to neutralize this alkali. The time required for neutralization to take place is noted. The band boundaries correspond to the successive maxima observed for the time taken by a definite increment of alkali to be neutralized; when a constant pressure is maintained over the column, volumes of eluate are proportional to time.

The total alkali used between band boundaries allows the sample composition to be calculated when the corresponding acids have been identified.

Identification is obtained by any of the classical methods, including the preparation of derivatives.

APPARATUS

The column, *A*, consists of a 1-inch Trubore borosilicate glass tube, *I*, a porous plate, *J*, a 35/25 ball joint socket head, *K* (inside ground slightly to exceed 25 mm.), an escape side tube for the nitrogen, *M*, a tip, *N*, which allows the eluate to fall onto the bend of tube *E*°, and a male 24/40 ₹ joint, *L*, which fits in the adapter.

The porous plate, which is of medium porosity, is slowly plugged on repeated use of the column, reducing the rate of flow and unduly increasing the time required for a run. Hence, the disk should be cleaned occasionally by allowing 1 *N* sodium hydroxide to flow through it for some time. It is then washed with dilute acid solution, rinsed with water, and dried.

The adapter *B*, which is never moved, is clamped firmly to a vertical stand, not shown in the diagram. (This stand also provides a fastening point for *A*°, *B*°, *F*°, *G*°, and column *A*.) At the top of the adapter there is a female 24/40 ground joint which receives the column, and at the bottom a male 34/45 ₹ joint, *R*, on which the collection flask is fitted. A capillary tube of 2-mm. bore, *O*, is sealed into one side and bent down, ending in a male capillary ground joint to receive the tip, *S*, made of capillary tubing (0.5-mm. bore); the extremity of the tip is constricted into a very fine outlet; hooks and stainless steel springs provide a mode of attachment and allow the tip to be removed for occasional cleaning. In the other side of the adapter tube *P* is sealed; this tube admits a stream of nitrogen adjusted by means of a screw clamp, *G*°, and bubbler, *F*°; the nitrogen reaches the receiver through inlet *E*°, the lower end of which bears a short bend and opens upward. A side tube, *Q*, shown in dotted lines, is sealed to the wall of the adapter, slanting upward and opening toward the operator; it is normally stoppered and is used only for eventual additions to the flask contents during a run.

The collection flask, *C*, is a 300-ml. ₹ 34/45 necked Erlenmeyer flask, provided with a horizontal capillary outlet, *T*, at the bottom; this outlet is normally plugged but provides a means for emptying the flask during long runs; suction is sometimes necessary to drain the flask rapidly.

The stirrer, *U*, is made from a section of iron nail (40 mm. long and 3 mm. in diameter) which is polished and chromium plated. *U* is driven by the rotation of a magnet, *W* (Alnico), fastened to a pulley, *X*, which is driven by a Meccano spring cord, *Y*; a small motor, *A*°, provides the necessary power. The pulley's shaft bearing, *Z*, is connected by the swivel arm, *B*°, to an upright; this permits the stirring device, *E*, to be swung to the right if desired.

The receiving flask is held in position by a rectangular support, *C*° (made from white, hard plastic), which can be swung to the left. The two swinging movements of the flask support on the one hand and the stirrer unit on the other allow the receiving flask to be removed and replaced very easily.

The buret, *F*, is equipped with a pure, surgical grade rubber tube, *H*, 4 mm. in diameter, which connects it to the side tube, *O*; a magnetic valve, *G*, keeps *H* closed tightly except when switch *H*° is closed. This valve allows the gap in *H* to be adjusted for any desired rate of flow of the alkali; it is operated by the alternating-direct current, 110- to 30-volt rectifier, *I*, which is connected to the main. This arrangement is much more satisfactory than a system of stopcocks; it eliminates any possibility of leakage and ensures a fast, yet precise delivery. The buret is filled by exerting a pressure on the alkali in bottle *Q*° with the rubber bulb, *O*°; release of the pressure is effected through the pinch clamp, *R*°, when the buret is full. Junctions *J*°, *K*°, and *L*° are made of vinyl plastic tubing. Tubes *M*° and *N*° protect the system from carbon dioxide. This filling arrangement is motivated by the necessity of avoiding stopcocks. *Q*° is supported by a ring, *P*°.

A scale, *T*°, is fastened to the column by elastic bands, *S*°. This simple system allows a fast zero adjustment to be made whenever the column is refilled during a run by opening the stopcock below reservoir *D*. As seen on the drawing, the column can be refilled without releasing the pressure. The pressure is supplied by line *V*, which is connected to a pressure regulator. Nitrogen from a cylinder equipped with a regulating valve is supplied to the regulator.

The pressure regulator, valve *G*, switch *H*°, and rectifier *I*° were obtained from the International Instrument Co., Los Angeles, Calif.

PREPARING THE COLUMN MIXTURE

Ramsey and Patterson (*8*, *9*) described the separation of the acids from C_6 to C_{10} using a column made of a mixture of silicic acid, methanol, bromocresol green, and ammonia; iso-octane was used as the eluting agent. The preparation is obtained by adding the four ingredients separately to a mortar and triturating the product until homogenized.

The determination of the optimum proportions involves building a column and observing its performance. One complication in this trial and error procedure is the evaporation of methanol and ammonia during the mixing; this varies according to the duration of the operation and with the surrounding temperature. Optimum conditions, which are critical, are therefore difficult to reproduce. In some cases, the separation of C_9 from C_{10}, never complete, may not be obtained at all; sometimes, despite a good start, the column structure unexpectedly develops cracks and crevices.

The authors have found that the column mixture lends itself to controlled preparation. One hundred parts by weight of silicic acid (Mallinckrodt No. 2844) will absorb about 60 volumes of absolute methanol and still retain the fluidity and "dryness" of the original powder. Because of this property the mixing can be effected simply by shaking the two ingredients in a stoppered bottle; in this way, losses are eliminated and a homogeneous and reproducible product is obtained.

The efficient column mixture used in the present method is prepared in that very simple manner using, instead of pure methanol, methanol containing an adequate amount of alkali.

The ratio of methanolic solution to silicic acid is critical. Too little methanol results in poor separation; an excess may cause the column to crack during use; besides, to different lots of silicic acid correspond slightly different ratios. Fortunately, a very simple criterion allows the determination of the correct proportion in all cases. When the right amount of silicic acid for a given quantity of methanolic solution is reached, the mixture no longer shows a tendency to adhere to the inner surface of the glass bottle in which it is being prepared. The test is sensitive and allows the reproduction of the correct composition, which is determined once and for all for a given lot. This is done as follows, using the quantities corresponding to column II.

To 21.5 ml. of the methanolic solution, placed in a 250-ml. wide-necked, ground glass–stoppered bottle, 33 grams of silicic acid are added rapidly and the bottle is stoppered immediately. It is cooled under a stream of tap water for 2 minutes, then alternately shaken by hand and tapped against a board of soft wood to dislodge the material clinging to the walls. After 2 to 3 minutes of this handling, mixing has occurred except for some material still adhering. The bottle is then cooled for a short while, opened to introduce about 1 gram of silicic acid, stoppered immediately and shaken again for 2 minutes. If by this time the powder no longer shows tendency to stick to the inner surface of the container, the preparation is completed; otherwise the sequence of cooling, addition of silicic acid, and shaking is repeated, decreasing the size of the additions until, with gentle shaking, the glass remains perfectly clean.

The light and mobile powder obtained is the desired mixture. Any following preparation can be obtained quickly and directly by adding *in toto* the amount of silicic used in the first preparation.

Sodium hydroxide was adopted as the alkaline agent. Comparative experiments have shown that it was in no way inferior to ammonia (used by Remsey and Patterson) or dimethylamine.

To detect eventual packing defects, it was found advisable to add bromocresol green to the methanolic solution used in the

preparation of column II. Oblique or ragged bands will induce poor separations. No indicator is necessary for the preparation of column I, which is made by mixing, in a 100-ml. bottle, 8 ml. of methanol-alkali solution and about 13 grams of silicic acid, and proceeding as for column II.

PACKING THE COLUMN

The column can be packed by either the slurry method or the dry packing method. In both cases a column of equal separating power is obtained, but each of the procedures offers particular advantages. The dry packing is more expeditious and the column obtained shows sharper color contrasts, but more experience is required to achieve a perfect packing in this way.

In both cases every effort is aimed at producing a column as homogeneous as possible, presenting an even and horizontal top level and exempt from elements of discontinuity such as gas bubbles and cracks. The packing requires the use of accessories, most of which are well known, such as the packing piston and paper disks. However, the use of Trubore tube in the apparatus allows precision fitting of these accessories, thus increasing appreciably the chances of success and allowing interchangeability. The accessories are shown in Figure 2.

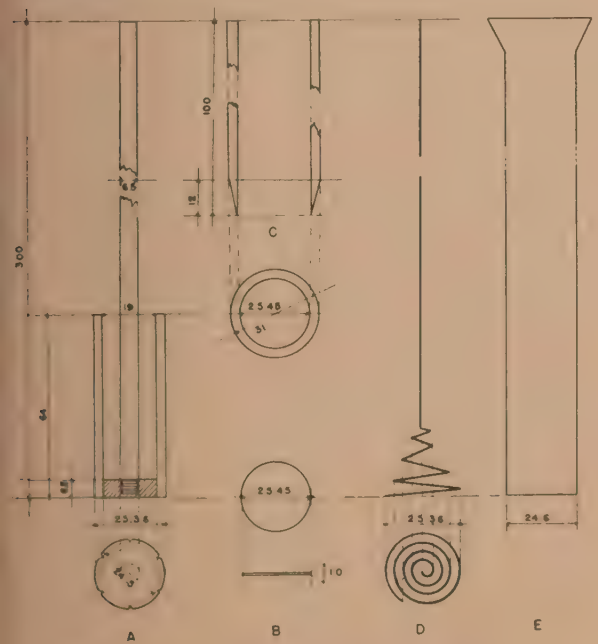

Figure 2. Accessories for Packing Column

The longitudinal grooves in the packing piston, *A*, allow the solvent to escape; the disks, *B*, are cut out of thick white blotting paper, using the sharp steel puncher, *C*, made to size. The disks should fit snugly even when wet. The spiral stirrer, *D*, is made of thick Chromel A wire. The glass filling tube, *E*, is used only for dry packing.

Slurry Method. The powder is poured into a 150-ml. beaker containing 50 ml. of iso-octane during gentle stirring with a glass rod; stirring is continued and the contents of the beaker are examined (through side and bottom) for unmoistened lumps of material which are crushed and air bubbles which are expelled. After a final rapid stirring, the slurry is poured into the glass column, using a wash bottle to complete the operation. Solvent is added, if necessary, practically to fill the apparatus. The spiral stirrer is immediately inserted and worked up and down in long strokes to homogenize the slurry; then, starting from the bottom and gradually reaching the top, the stirrer is moved in short rapid strokes to force air bubbles to rise and leave the slurry. A strong lateral light is very useful in detecting bubbles.

The reservoir is then clamped on and pressure applied gradually up to 30 to 35 mm. of mercury. The slurry settles, usually with an even, horizontal top level; if this is not the case, tapping on the side of the column with the fingertips will correct the defect, which should be dealt with as early as possible.

When the slurry has nearly reached maximum compression, the pressure is slowly released, the reservoir disconnected, and a blotting paper disk inserted obliquely until completely immersed in the liquid. The packing piston is then inserted and the disk carefully pushed down until it almost touches the top of the slurry. The reservoir is then clamped on and pressure reestablished. In no case should solvent be added before the disk is in position.

When maximum compression is attained, the pressure is released, the reservoir disconnected, and the packing piston inserted and carefully lowered, using a gentle pressure to put the disk in contact with the slurry. After the supernatant solvent has been poured off, the column is ready for use.

Dry Packing. The filling tube is inserted into the perfectly dry column; the powdery mixture is poured into the filling tube, which is then seized by one hand and lifted slowly and regularly while being rapidly tapped on the side with the fingertips.

The column is then fitted to the 24/40 $\overline{\$}$ neck of a flat-bottomed 250-ml. flask; a piece of filter paper is inserted between the two ground surfaces to prevent freezing of the joint.

This assembly is then loosely clamped to a support; the clamps are adjusted to allow and guide as vertical as possible a motion of the column and flask system. The latter is then seized by one hand at the joint and its bottom is gently tapped against the bench, the tapping being continued until maximum settling has occurred; if at any time during this operation the top level does not remain horizontal, side tapping with the fingertips should be applied.

The packing piston is then used to push, gently but firmly, a blotting paper disk in contact with the material.

The column is then replaced on the adapter, the reservoir clamped on, and solvent run in and allowed to flow down by gravity. When the percolating solvent has reached the bottom of the column, the supernatant solvent is poured off; the column is ready for use.

ADDING THE ACID MIXTURE

The small amount of solvent still covering the disk is left to drain by gravity into the column; as soon as the disk begins to appear, a small volume of the iso-octane solution of the mixture to be analyzed is allowed to run onto it from a pipet. The tip of the pipet should be located centrally and very close to the disk. The ideal volume would be just large enough to cover the disk; however, the smallest practical amount ensuring uniform density of coverage is 0.75 ml.

The solution is left to drain by gravity and as soon as the disk begins to appear, 1 ml. of iso-octane is added and left to drain in a way similar to that used for the solution. This operation is repeated once, after which the column is filled with solvent, the reservoir clamped on, scale $I°$ (Figure 1) adjusted to zero, the time read, and the pressure applied.

The acid mixture is conveniently added with a long pipet made of 2-mm. capillary tubing bearing two notches 25 cm. apart and a finely drawn tip. The volume between the marks is carefully calibrated and should be delivered in about 10 seconds.

DEVELOPMENT, ELUTION, AND TITRATION

The receiver, containing 10 ml. of pure methanol, is placed in working position. A brisk stream of nitrogen is directed through it for about 5 minutes; the gas flow is then reduced to a count

Table I. Part of Typical Record Sheet

Vol. *a*, 0.01 *N* NaOH, Ml.	Time Min.	Time Sec.	Ratio, $\frac{t(\text{Sec.})}{a(\text{Ml.})}$	Vol. Eluate, *E*, Scale, Ml.	Ratio $\frac{E(\text{Ml.})}{t(\text{Min.})}$
0	0	0	. .	0	. .
0.1	5	0	. . .	7.5	1.50
0.2	16	0	5600	24.0	1.50
0.3	35	35	5750	53.75	1.51
0.4	36	05	300	. . .	. .
0.8	37	00	137	. . .	. .
1.4	38	05	92	. . .	. .
2.0	39	20	125	. . .	. .
2.4	40	35	185	. . .	. .
2.6	41	20	225	61.75	1.49
2.7	41	45	250	. . .	. .
2.8	42	20	350	. . .	. .
2.9	44	00	1000	66.0	1.50
3.0	44	20	200	. . .	. .
3.4	45	20	125	. . .	. .
4.0	46	10	80	. . .	. .

of about 2 bubbles a second. The first 5 minutes are employed in adjusting the pressure to obtain the desired rate of elution judging by the number of drops falling, per minute, from the tip of the column. Any rate between 1 and 2.5 ml. per minute is convenient. The buret is filled with 0.01 *N* sodium hydroxide–phenolphthalein solution. The stirrer is set in motion.

The operations that follow are illustrated by Table I, which shows the first section of a chart recorded during a typical run involving column II and a mixture of acids from C_{12} to C_7.

The first 0.1 ml. of alkali was added after 5 minutes of elution to neutralize whatever foreign acidity the receiver may contain. Decolorization was rapid and another 0.1 ml. was added; this was decolorized completely only after 11 minutes and the following 0.1 ml. after 9 minutes and 35 seconds (the time is read to the nearest 5 seconds). However, the next 0.1 ml. lasted but 30 seconds; thus the surge of the C_{12} acid was clearly indicated.

The next addition, therefore, was increased to 0.4 ml.; this was neutralized in 55 seconds and the ratio time-alkali fell from 300 to 137; consequently, the following additions were increased to 0.6 ml. With the second, the ratio $\Delta t/\Delta a$ rose from 92 to 125; thus, the following addition made was only 0.4 ml. and, as $\Delta t/\Delta a$ still increased, was 0.2 ml., and then 0.1 ml. in the following ones. The ratio finally reached the value of 1000; with the next 0.1-ml. addition it fell to 200, unmistakably showing the start of the next acid.

From then on the pattern of the analysis shows the same alternation of alkali addition, recording of the neutralization time, new alkali addition, and so on, the time-alkali ratio indicating whether the volume of alkali is to be increased, maintained, or decreased for the next addition. When the band is very strong (more than 5×10^{-6} mole of acid), as much as 1 to 2 ml. of alkali may be added at one time. The lower limit, on the other hand, is 0.1 ml. (10^{-6} mole).

The time-alkali ratios clearly show the band limits and the amount of alkali used for each acid. In the example shown, the C_{12} band required $2.9 - 0.3 = 2.6$ ml. of 0.01 *N* alkali and therefore contained 5.2 mg. of lauric acid.

The fifth column of the table shows occasional readings made on the column scale. As seen by the figures in the sixth column, the ratio of volume of eluate to time is constant. Thus the values of the second, third, and fifth columns enable the determination of the volume eluted at any time.

As the elution proceeds, the successive band volumes increase in size. Consequently, there is a progressive increase of the time-alkali ratios. At the same time, the gap between bands increases.

With column II, the gap between C_7 and C_6 becomes very large and the elution of C_6 is extremely slow. Thus for all practical purposes, the operation on the long column is terminated after the elution of heptanoic acid, when 250 ml. of eluate have been collected.

From column I, the acids from C_{12} to C_7 are all eluted in the first 80 ml. of eluate. Their separation is not complete, but the values of the time-alkali ratios clearly indicate the presence of each acid and even allow a rough estimation of their respective amounts to be made. The separation of C_7 and C_6 is satisfactory, however, and from then on, the separation of the lower acids is sharp. The elution of butyric acid is complete after 270 to 300 ml. of eluate have been collected; the propionic acid band is so distant, however, that for all practical purposes the elution has stopped; iso-octane is then replaced by a 10% (v./v.) ether–iso-octane solution; only propionic acid is eluted; after a little over 100 ml. have been collected, the eluate is acid-free again; at this moment, pure ether is used and acetic acid washed down very quickly.

An abrupt increase of the time-alkali ratio indicates the end of this band, the acid slowly eluted thereafter being extraneous.

If acids above C_9 are present in the sample, their sodium soaps may promote undesirable emulsions in the receiver. These are broken by 2 or 3 drops of saturated, neutralized sodium chloride solution dispensed from an eye dropper. The latter is installed, at the beginning of the operation, through the cork stopper inside tube *Q* of the adapter (Figure 1).

Table II. Values Found and Calculated for Mixture of Acids from C_2 to C_{12}[a]

Acids	Calculated, mg.	Column I Found, mg.	Column I Recovery, %	Column II Found, mg.	Column II Recovery, %
C_{12}	7.92	8.18		8.18	103.3
C_{10}	7.21	6.82		7.28	101.0
C_9	7.92	6.27		8.14	102.7
C_8	7.53	9.45		7.75	102.9
C_7	6.96	6.88	98.9	6.70	96.3
C_6	6.01	5.62	93.5		
C_5	7.55	7.01	92.9		
C_4	9.07	8.60	94.9		
C_3	8.69	8.40	96.7		
C_2	8.75	8.87	101.4		

[a] Hendecanoic acid was unavailable when this mixture was analyzed.

Table III. Results from Two Acid Mixtures (C_6 to C_{12}) Containing Acids in Unequal Amounts

(Column II used in both cases)

Acids	Mixture B Calcd., mg.	Mixture B Found, mg.	Mixture B Recovery, %	Mixture C Calcd., mg.	Mixture C Found, mg.	Mixture C Recovery, %
C_{12}	3.06	3.19	104.3	10.18	10.31	101.3
C_{10}	15.55	15.58	100.5	1.360	1.366	100.5
C_9	3.92	4.10	104.5	7.52	7.58	100.8
C_8	13.75	13.92	101.2	2.125	2.125	100.0
C_7	3.92	3.95	100.7	8.14	8.14	00.0
C_6	14.72	[a]		1.735	[a]	

[a] Development was not carried out beyond heptanoic acid.

IDENTIFICATION

While the values of the threshold volumes are too dependent on acid mixture composition to be used for positive identification, they offer very valuable clues as to the probable nature of the acids involved. Very often a doubt may exist only concerning the identity of one or two; in such case, confirmation can be obtained by comparing the chromatogram just obtained with that obtained with the same mixture to which known amounts of these acids have been added. Much more definite conclusions can be drawn when this comparison is made with a chromatogram obtained from a synthetic mixture made to represent the suspected composition: Identical mixtures show practically identical chromatograms. Definite evidence, however, requires the preparation of derivatives. The separate fractions of pure acids are obtained by repeating the elution without titration, using the previously obtained chromatogram as a guide for changing the receiver.

The following method can be used to prepare, from 5×10^{-6} mole of acid, enough *p*-bromophenacyl bromide derivative to allow melting point, mixed melting point, and elementary microanalysis to be made.

The aqueous solution of the sodium salt containing about 5×10^{-6} mole is evaporated down to 0.5 ml. It is transferred to a small test tube (12 mm. in diameter) and the volume made up to 1 ml. with water. One milliliter of an alcoholic solution of pure *p*-bromophenacyl bromide (3×10^{-6} mole of the reagent) is added, and the tube is sealed and heated 1 hour in an oven (90°). The cooled tube is open; if the precipitate is poor, 1 drop of water is added. The mother liquor is carefully removed and the wet crystals are placed on a porous plate, where they are repeatedly washed by 1 drop of 50% alcohol and dried. The crop is at least 15 mg.

Alternatively, the silver salts can be prepared and evidence obtained from their x-ray powder photograph (*6*).

Experimental. Reagents. Silicic acid, Mallinckrodt, analytical reagent, No. 2847 (100-mesh, specially prepared for chromatography) or No. 2844. (No. 2847 is more uniform from lot to lot. Several lots of 2844 have been found superior; however, only one was found inadequate.)

Methanol Solution A. Bromocresol green, 0.6 gram; 7.5 ml. 1 *N* sodium hydroxide (aqueous); absolute methanol, to 1 liter.

Methanol Solution B. Solution A without indicator.

Iso-octane. Phillips Petroleum Co. pure grade, dried over calcium chloride and redistilled.

Standard Titrating Solution. About 0.01 *N* sodium hydroxide

50% aqueous ethanol. The solution contains 0.3 gram of phenolphthalein per liter.

Acid Mixtures. The results obtained for the analysis of three synthetic mixtures are given below. Commercial acids (Eastman Kodak, white label) were used in all experiments. The acid values of each acid were determined and the necessary corrections (0.5 to 1%) were made.

Standardization of Titrating Solution. An aqueous solution containing 1 gram of sublimed benzoic acid per liter was prepared. The receiver, containing 50 ml. of water, was placed in working position. The column was replaced by a cork stopper bearing a 15-mm. hole. The stirrer was set in motion and a brisk flow of nitrogen was directed through the receiver for 5 minutes; it was then reduced and alkali introduced slowly until a faint pink coloration persisted. Ten milliliters of standard benzoic acid solution were then added to the contents of the receiver, the pipet being lowered through the hole in the cork stopper. Alkali was added until a faint pink coloration persisted. The strength of the alkali solution was found to be 0.0113 *N*. The same technique is used to determine the total alkali corresponding to 0.75 ml. of acid mixture solution; in such case, isooctane is used instead of water in the receiver.

Results, Discussion, and Conclusion. Mixture A, containing acids ranging from C_2 to C_{12}, was analyzed, successively, on column I and column II. Column I was made by mixing 8 ml. of methanol solution B and 13 grams of silicic acid No. 2844 in a 100-ml. bottle. Column II was made of 21.5 ml. of solution B and 36 grams of the same silicic acid. Table II shows the results. Recoveries for the acids from C_{12} to C_8 are not indicated for column I, as the separations were not sharp. As usual, the operation on column II was not carried out beyond heptanoic acid. Some recoveries in this analysis are on the low side; recoveries are usually better than 95%. A good analysis is shown in Table III. In this table are listed results obtained with column II on two mixtures, B and C, made by alternating low and high amounts of the acids from C_{12} to C_8. In both cases the column was made of 21.5 ml. of solution A and 36.5 grams of silicic acid No. 2844. The results show that good recoveries can be obtained when the amounts of individual acids range from 1 to 15 mg.

DICARBOXYLIC ACIDS FROM C_4 TO C_{10}

When the present investigation was undertaken, there was no general method for the separation of dicarboxylic acids. Recently, however, papers dealing with this subject have been published. Marvel and Rand (*5*) have succeeded in separating either the even- or the odd-numbered acids, using silicic acid as the support, and water and chloroform-butanol mixtures as stationary and mobile phases, respectively. A complete, though not quantitative separation of the acids from succinic to brassylic has been effected by Bergmann *et al.* (*1*); silicic acid was used as the support, while a water-alcohol mixture served as the stationary phase and benzene as the eluting solvent.

The method and techniques proposed by the present authors for the separation and quantitative determination of the monocarboxylic acids apply almost entirely to the dicarboxylic acids from C_4 to C_{10}: The same procedure is applied in the preparation of the column mixture for which silicic acid is also used; the apparatus and the titration technique are identical. The dry packing, described above, is the method employed; identification is obtained by the same methods. The similarity extends to the use of two successive operations, the first carried out on a short column (C_7 to C_4), the second on a long column (C_{10} to C_7). Consequently, the detailed description which follows mainly insists on differences between the two procedures.

COLUMN MIXTURE

The material for the column is obtained by shaking water and silicic acid in a stoppered bottle. The correct proportions are determined for any new lot of silicic acid (Mallinckrodt 2844 or 7847): there should be just enough acid to make a powder which no longer shows any tendency to stick to the walls of the bottle. Approximate proportions are 1 part of water for 3 parts of silicic acid. The long column (column II) requires, moreover, 3 drops of 1 *N* aqueous sodium hydroxide, added to the water (10 ml.) prior to mixing. This may not be necessary with fresh material; however, the initial resolving power is lost after a relatively short time of exposure to the air, presumably through carbon dioxide contamination; the addition of alkali restores this property. Increasing the addition above the proportion given above does not further improve the resolving power, while it appreciably retards the elution of the acids; the resulting stretching of the bands renders the detection of the band boundaries uncertain. The short column (column I) (3.3 ml. of water) does not require alkali.

PLACING ACID MIXTURE ON COLUMN

Here, a "powder mixture" is used instead of a solution of the acids. One of the conditions for a good separation is that the sample be of as small a volume as possible. Yet the sample should contain enough of all the acids. Solutions made of solvents or mixtures of solvents fulfilling this condition (methanol, ether, acetone, etc.) initiate a blurring of the bands, resulting in poor separation.

The powder mixture, being a homogeneous dispersion of the acids in silicic acid, is an adequate substitute for the ideal "liquid" solution with added advantages: It does not evaporate, can be made relatively concentrated, and can be measured more conveniently (by weighing).

The procedure consists in dissolving the acids in acetone and shaking the resulting solution with enough silicic acid to obtain a powder which does not show any tendency to stick to the walls of the stoppered bottle in which the mixing is performed; excess silicic acid may be used. The bottle is then placed open in a low temperature (40° to 45°) oven; the acetone-free powder is left at room temperature to equilibrate with atmospheric moisture (constant weight). After a final, thorough shaking, it is ready for use.

From 0.75 to 1.5 grams of a powder mixture which may contain from 1 to 5 mg. of each acid per gram is weighed and placed on top of the blotting paper disk after the latter has been pressed against the dry packed column material. After this has been leveled (tapping), a second blotting paper disk is pressed against it, and solvent is added and left to percolate by gravity. While this is proceeding, the receiver is placed in working position and swept with nitrogen. After the solvent has reached the bottom of the column, the scale is adjusted to zero, the time noted, pressure established, and the analysis pursued as for the monocarboxylic acids.

ELUTION, DEVELOPMENT, AND TITRATION

Five per cent (v./v.) butanol-chloroform solution (CB_5) is used as the mobile phase. From column I, used for the first operation, sebacic acid would start eluting after 10 to 12 ml. of eluate have been collected; azelaic acid, in the absence of sebacic acid, would appear after 15 to 17 ml.; suberic after 25 ml.; pimelic after 40 ml.; the threshold volume of glutaric acid is about 67 ml. CB_5 is replaced by CB_{10} (10% solution) at that moment. The elution of the last two acids, otherwise very slow, then proceeds normally, the threshold volume of adipic being 105, that of succinic acid, 175. If this first operation has shown the presence of acids above C_7 (acid in the first 40 ml.), column II is set up and eluted with CB_5 exclusively. When this column is used, sebacic acid appears after 36 ml.; the threshold volumes of the succeeding acids are: azelaic, 57 ml.; suberic, 93 ml.; pimelic, 120 ml. The next band is so distant that the elution practically stops after pimelic acid has been eluted (180 to 190 ml.). A change from CB_5 to CB_{10} forces the elution to resume its course, but no practical gain results.

All threshold volumes cited are averages and variations depending on sample composition are to be expected.

The titration is carried out in exactly the same manner as for the monocarboxylic acids except for one detail. The indicator is slowly extracted from the aqueous phase by the chloroform phase. This affects the titration only when the elution of the acids is very slow and contact between the two phases is sustained for long periods without further addition of indicator; the latter may, in such case, be totally extracted before actual neutralization has occurred. This may happen at the end of the

Table IV. Recoveries of Acids C_4 to C_7 on Column I and C_7 to C_{10} on Column II

Mixture A, Column I				Mixture B, Column II			
Acids	Calcd., mg.	Found, mg.	Recovery, %	Acids	Calcd., mg.	Found, mg.	Recovery, %
C_7	2.93	2.77	94.5	C_{10}	2.23	2.03	91.1
C_6	2.93	2.80	93.0	C_9	2.23	2.22	99.4
C_5	2.93	2.98	101.7	C_8	2.69	2.61	97.0
C_4	2.93	2.91	99.3	C_7	2.23	2.28	102.2
C_7	1.95	1.81	92.8	C_{10}	2.23	2.04	91.5
C_6	1.95	1.84	94.3	C_9	2.23	2.22	99.4
C_5	1.95	2.05	105.2	C_8	2.69	2.61	97.0
C_4	1.95	1.96	101.0	C_7	2.23	2.12	96.1

C_7 band from column II and at the end of the C_4 band from column I. If, however, 1 drop of 1% alcoholic phenolphthalein solution is added at that point, the pink coloration of the top layer reappears if alkali is still present. To allow this check to be made, an eye dropper containing the extra indicator is fitted, from the beginning of the operation, in the cork stopper placed inside tube *Q* of the adapter.

Experimental. Reagents. Silicic acid, Mallinckrodt No. 2844 or 2847.

Distilled water, 1 *N* sodium hydroxide.

CB_5, CB_{10}. Chloroform (U.S.P. or C.P.), purified by passing through a column of aluminum oxide to ensure a low blank (0.06 ml. of 0.01 *N* sodium hydroxide for 20 ml.). Butanol, Eastman Kodak, white label.

Sodium hydroxide solution, 0.01 *N* (titration).

Acetone, alcohol, acid-free, redistilled.

Dicarboxylic acids. All were Eastman Kodak white label without purification except suberic acid, which was synthesized (*10*), and glutaric acid, recrystallized from hot benzene. The acid values were within 1% of theory. Melting points were correct, but the range was 3° for sebacic acid.

Acid Mixtures Analyzed, Column Used. Duplicate analyses of two mixtures, A and B, were made. Mixture A (C_4, C_5, C_6, and C_7) was analyzed on column I (3.3 ml. of water, 10.1 grams of silicic acid, Mallinckrodt No. 2844). The powder mixture was made of 5 ml. of acetone solution containing 25 mg. of each acid and 12.8 grams of silicic acid. The first analysis was made using 1.50 grams of the powder mixture, the duplicate with 1 gram. Mixture B was analyzed on column II (10 ml. of water, 3 drops of 1 *N* sodium hydroxide, 30.5 grams of silicic acid 2844). The powder mixture was made of 5 ml. of acetone so tion containing C_{10}, C_9, and C_7 (25 mg. each) and C_8 (30 m 16.8 grams of silicic acid were mixed with this solution. each duplicate analysis 1.5 grams of the powder mixture w used.

RESULTS, DISCUSSION, AND CONCLUSION

Table IV shows that recoveries are about 95% or better, exc for sebacic acid. Impurities in sebacic acid were no doubt par responsible for the discrepancy observed: When purified seba acid was used, the recovery was always higher, although c sistently 3 to 5% too low; this suggested that some other ca was involved. It is suspected that the blank correction, as tained, is systematically too high in that region. Quantities acids as low as 0.5 mg. and as high as 7.5 mg. have been estima successfully. The separations of C_{10} from C_9 and of C_8 from are not as sharp as the others, a consequence of the even- solubilities alternation which is not entirely compensated for the solvent combination used.

Other results indicate that hendecadioic acid would be separa very satisfactorily on column II and that the acids up to brassy could be separated on a somewhat higher column (15 ml. of wat

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Recent Advances in Various Technological Aspects of Handling Fish and Fish Products

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The present acute world shortage of food has resulted in considerable research concerning the nutritive value of products derived from both plants and animals. It is now well known that fish flesh constitutes one of the most valuable sources of animal protein which is so essential for proper growth of both man and farm animals. From this standpoint, fish has been shown to be at least as nutritious as meat, and, in countries where fish is relatively plentiful and its consumption is low, attempts are being made to increase the use of fish in the diet. Investigation has now shown that the nutritive value of fish and fish wastes in the feeding of livestock does not depend solely on its content animal protein. The digestive tract and internal organs are excellent sources of certain-watersoluble vitamins that are found in the condensed fish solubles forming a by-product of the fish meal industry, and found to some extent in the fish meals themselves. Many years ago it was shown that fish liver is a good source of the anti-pernicious-anaemia factor, and it has recently been established that fish viscera contain considerable quantities of a possibly related "animal protein factor" which is necessary for adequate growth and productivity of farm animals. This factor is probably vitamin B_{12}. Pacific Northwest experiments have shown that fish viscera form an excellent food for fish in hatcheries, and have suggested that the reason for this lies partly in the ability of such material to supply a necessary animal protein factor (vitamin B_{12}?) in the fish diet.

The problem of spoilage and resultant waste of fresh fish continues to occupy an important position in research programmes. It has long been realized that improvements are required in existing techniques of icing fish on vessels. Recent developments have included a study of insulated vessels, of specially constructed fish holds in which lower temperatures can be maintained by combining icing with mechanical refrigeration, and of germicidal ices. The necessity for strict sanitary procedures in handling and processing fish as landed is slowly becoming appreciated. Advances in this field include the adoption of sanitary metal filleting tables equipped with removable boards and flumes or belts for conveying fillets and offal. Machines have been designed for washing fish before filleting, and also for filleting fish. Brine dips for preventing drip in defrosted fish, and application of small amounts of relatively harmless substances to retard bacterial spoilage or oxidative rancidity in frozen fillets have been recommended and in certain instances have been adopted. Improved vapour-proof packaging materials for fillets, including aluminium foil, polyethylene glycol, pliofilm and certain grades of cellophane have been studied, some of which retard drying and, to some extent, appear to hinder development of oxidative rancidity. The value of various detergents in washing fish plants and vessels and of subsequent application of germicides with and without addition of anti-corrosives has been studied.

Freezing is now a well-recognized method of preserving fish, but it is lamentable that so little attention is sometimes paid to proper storage conditions. Rapid freezing and a constant storage temperature of 0 degrees F, or preferably —25 degrees F, in the case of fatty fish, should be adhered to. Even with optimum storage conditions, slow alterations occur which are probably, in part at least, due to enzyme action and drying out or desiccation of the exposed surfaces is always a danger. Drying can be almost eliminated by use of jacketed cold-storage rooms, adequate glazing of whole fish and proper packaging, and certain techniques are available whereby rancidity development can be retarded considerably. Unfortunately, toughening of the flesh (denaturation) and loss of flavour occur even at low storage temperatures, and scientific means of overcoming these alterations remain to be discovered. Chemical substances have been found which prevent ice glazes on fish from cracking, and others are known which, when incorporated in glazes, will retard rancidity development and attendant rusting of exposed fat. Possibilities in increasing fish catches and improving quality by employing refrigerated ships have been realized. Thus in the United States, the 8,800 ton "Pacific Explorer" has landed over 2,000 tons of frozen tuna after a single trip to distant waters. In one trip the British whaling factory ship "Balena" landed 4,000 tons of edible meat, 3,200 tons of cattle fodder and 163,000 barrels of edible oil. Much time is being devoted to a study of railway and other refrigerated transportation of fish on land.

Advances in canning technology include the use of aluminium cans in certain Scandinavian countries, and of the development of corrosion-resistant can enamels. Many new canned marine products have been evolved and in the preparation of these smoke, salt, tomato puree, spices, thickening agents and oils of vegetable and marine origin have been used. The brown discolouration which frequently occurs in flesh of certain marine white-fleshed fish during canning has been shown to be due largely to the non-enzymic browning reaction and remedial methods are being investigated. Some of the internal corrosion of cans in the case of fish products has been attributed to the chemical action of trimethylamine oxide. Several investigations regarding the optimum conditions for processing crab meat have been carried out and appropriate recommendations regarding the use of acid dips and processing temperatures and times have been made. A notable advance in salmon canning in which a skinless-boneless product is produced with the aid of patented skinning and filleting machines has aroused considerable interest.

Considerable attention is being given to the possibility of preparing by-products from fish. Insulin was prepared in Canada from fish pyloric caeca almost thirty years ago and, in view of a possible world shortage of this pharmaceutical experts in Denmark, South Africa, Canada, Great Britain and other countries are investigating its occurrence in whales and sharks.

Sterols are required in the preparation of certain hormones and the D vitamins. Cholesterol and other sterols occur in and have been insolated from mussels, fish meal and fish oils.

Fish oils are still the only commercial source of vitamin A, though their position is rather uncertain in view of the possibility of commercial production of a synthetic product. Modern solvent fractionation procedures have greatly facilitated preparation of vitamin A concentrates from low-potency fish oils.

Synthetic egg white, protein hydrolysates and peptones have also been prepared from fish flesh.

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Wandering Versus Homing in Salmon

By
A. G. HUNTSMAN

ALTRINCHAM
JOHN SHERRATT AND SON

WANDERING VERSUS HOMING IN SALMON

By A. G. Huntsman

Consulting Director, Fisheries Research Board of Canada

THERE has been general belief that migrating animals are able to direct their courses between breeding grounds and feeding grounds. For salmon this has been expressed (H. Munro Fox, *The Personality of Animals,* Revised Edition, New York, 1947) as that "the young salmon . . . swim down to the sea" and "learn the way" for later return home. There is no difficulty in retaining this belief in the absence of the pertinent facts. Our investigations of the last eighteen years have failed to substantiate the prevalent views on salmon migration and have given a wealth of data which indicate a very different behaviour on the part of these fish than what has been in mind.

It is natural to expect that, if salmon do return from feeding grounds in the sea to breeding grounds in rivers, there must be some homing mechanism to explain it. With this expectation one naturally rejects or ignores any other mechanism that may be revealed in study of salmon migration. However, from the practical standpoint it does not matter whether the salmon gets back to its breeding grounds by a homing mechanism or by a wandering mechanism. Those who are practical and not wedded to theory will doubtless be prepared to consider that there is some merit in a wandering mechanism, if it satisfactorily explains why salmon return or fail to return to rivers at the desired times, when a homing mechanism does not do so.

As a background for discussion of this matter of return, it may be stated that careful study of the descent of young salmon or smolt to the sea has shown that they are carried down and fight the current when in shallow water. Consequently, in shallow water they descend mostly after dark when they do not see that they are being carried over the bottom

and when, of course, they cannot learn the way for return. In very shallow water, they do not descend even after dark because they can feel that they are being carried over the bottom and accordingly fight the current. Under such conditions, they descend only with a rise in water after a rain. As a consequence of this behaviour smolt descend streams very much less quickly than if they swam down and indeed much less quickly than if they let themselves be carried down.

The smolt are carried downstream because they wander. In contrast to this, before becoming smolt, the young salmon, as parr, settle down in the streams and occupy and defend territory, now in one place and now in another. That the smolt should be carried down into the sea is an advantage, since this takes them into the river outflow where a good supply of planktonic food is readily brought to them from outer waters in the deep return current that compensates for the sea water that flows out at the surface when mixed with river water.

When the fat adult salmon as grilse or larger fish cease from this good feeding and wander, in the river outflow, they meet two features that may direct them back to breeding grounds in the river. When they are in a current and near enough to the bottom to see or feel that they are being carried over it, they head upstream. Thus, the outflowing current may direct them back up the river. When in wandering they reach the shore or the contour line of the bottom for the depth at which they are swimming, they must change direction. This usually results in their leading along the shore or the contour line. Fishermen are well acquainted with this behaviour of wandering fish and put leaders on their traps to direct fish into them. Such salmon in a river outflow as lead along the shore or contour line in the right direction will reach the river mouth where at their depth there may be a current to direct their wandering upstream. Wandering can in this way be very effective in ensuring good return of salmon from feeding grounds in the sea to breeding grounds in rivers.

Facts show that the idea of homing has some good basis beyond casual return by wandering. For the Moser River, we have been able to judge the extent to which recognition of home water is a factor in return. Smolt from its two branches at a fork were distinctively marked. The branches were not equally suitable for ascent. On return as adults, the marked fish

of both kinds ascended both branches, but on the average 80 per cent of the fish did ascend the home rather than the foreign branch. In the sea, the marked Moser salmon were taken mostly in the Moser outflow; but they were also taken in the outflows of certain neighbouring rivers in both directions along the Nova Scotia coast, which they would readily reach in wandering. There was one exception, however. They were not taken in the large outflow of the St. Mary River, which drains country very different geologically and agriculturally from that drained by the others of these rivers including the Moser, although the St. Mary River provides a very good salmon fishery both for nets in its outflow and for rods above the head of tide. These facts indicate that in the sea Moser salmon avoid very foreign water, but not water sufficiently similar to the home water. Conversely, the marking showed that many foreign fish, presumably from neighbouring rivers, not only entered the Moser outflow, but ascended the Moser River above the head of tide, sometimes exceeding the native fish in numbers. Recognition of home water does not direct the fish home, but may stop the wandering. Very foreign water may actually be avoided by the fish.

Comparative failure in return of the salmon is shown in the two rivers that we have studied most thoroughly, the Margaree River of the inner coast of Cape Breton Island and the Moser River of the outer coast of the mainland of Nova Scotia. Critics can easily dismiss both rivers as being atypical, but they are angling actualities that need to be dealt with. The Margaree is a most notable salmon river, with beautiful water and magnificent scenery of valley and gorge, to which anglers resort from far and wide. The Moser is a small river, which few salmon larger than grilse ever ascend. These grilse or "jumpers", the local name, are mainly taken by a surprisingly large proportion of anglers from the 250-odd souls that make up the population of the lumbering village of Moser River, which is located around the head of tide.

It is a curious fact that the salmon in the Moser outflow that are larger than grilse are taken mainly at the head of Necum Teuch Bay, as congregated on the right side, looking inwards, of the mouth of the two-mile-long Moser estuary. Two nets close to this mouth take the greater part of the fish. This is in accordance with the way in which fish wandering at

some depth will be concentrated by being carried in the return current that compensates for the sea water that is mixed with the river water near this mouth and carried seaward at the surface. The really striking fact, however, is that these salmon of seven pounds or more in weight are taken to only a very slight extent by the nets in the estuary or by rods and our experimental traps up the river. Yet the small grilse of three to four pounds weight enter the estuary and ascend the river in large numbers. This holds for both the native marked fish and for the evidently foreign fish.

That small salmon should readily enter the Moser estuary and ascend the river and that large salmon should for the most part fail to do so, even when congregated at the mouth of the estuary, raises the question: What is the difference between the small and the large? A very definite difference that size makes in the behaviour of salmon, as can be readily observed in the parr stage, is that the larger they get the deeper they go in the water. Therefore, at the mouth of the estuary the grilse will not in their wandering be swimming as deeply as the larger fish. As it happens, the estuary is shallow. Consequently, grilse in leading along the contour line at their depth will be led into the estuary, but the larger salmon will not. Nothing more seems required to explain the comparative failure of the larger Moser fish to enter the estuary. If they had learned the way, they would rise to a higher level on reaching the mouth and then easily enter.

The Margaree River also has a shallow estuary, which discharges not into a bay, but into the Gulf of St. Lawrence on a straight coast. The Margaree salmon are practically all large fish that have been two or three years in the sea and that weigh from eight to twenty-five pounds or more. It has been a matter of bitter complaint by anglers that in some seasons these salmon are not available in the river, even when taken in large numbers by nets on the coast. The nets have been blamed for the poor angling catches, although tagging, by the Fisheries Research Board in 1935, 1936 and 1937 and in recent years by the authorities of Nova Scotia, has clearly shown that the salmon do not enter the river to any extent in relatively dry periods, even when released close to the mouth of the estuary.

Those with the longest experience on the river maintained that many years ago the salmon did enter to a greater extent than recently, although their entrance has always been rather uncertain and greatly dependent upon

weather. I was inclined to dismiss this claim as being nothing more than "fond recollection" of the "good, old days". But old angling records seemed to give some substance to the idea that angling then had on the whole been better.

As it happened, it was possible in our investigations not to study the Margaree River as it had been long before, but to compare it with a neighbouring river. The Cheticamp River, fifteen miles to the north, drains high tableland, as does the North-East Margaree River, in which nearly all the Margaree rod salmon are taken. The two are quite similar in character, including the size of their fish. These large fish enter the Cheticamp River mainly in June, just after the Gulf water, which is ice-cold in winter, has become warm enough for them to move actively, which is too late for action on them by the spring floods. They do not, however, enter the Margaree till somewhat late in the season, and their entrance may be too late for angling. Heavy rains bring them in rather early, but they may not enter until stoppage in the fall of transpiration by land plants makes rains more effective in causing freshets.

Why should their be this difference between the two rivers? The Cheticamp has an even shallower estuary than the Margaree, *but* it has a sand bar across the mouth, which neither the Margaree nor the Moser possesses. With this sand bar to hold the level of the inside water high, brackish estuarial or pure river water is flowing out from the estuary in a distinct stream at practically all stages of the tide. Through the mouths of the larger Margaree and Moser estuaries, particularly with low river discharge, their saltier estuarial water flows out with ebbing tide and the sea water flows in with flooding tide. In the Cheticamp, current directs fish into the estuary most of the time, but current directs fish out of the Margaree and Moser estuaries almost as much as in.

If a sand bar at the mouth of the Cheticamp River makes it an early river as compared with the Margaree, has there been any change in the Margaree which would make the fish enter less promptly than they formerly did? The Margaree fish, like the Cheticamp fish, are moving along the coast, starting early in June, but largely fail to enter. Fortunately there are records of what the mouth of the Margaree estuary was like in the 19th century, and I have a blueprint of a survey made in 1871.

There was at first a sand bar across the mouth of the estuary, but a channel was dredged through it to make the estuary into a harbour, which is much needed on such a straight coast. Winter storms tended to fill the channel and made repeated dredging necessary. To obviate the great expense involved, breakwaters were built out from the sides of the narrow mouth of the estuary to direct the tidal outflow and inflow so that these would scour the bottom of the channel and keep it from being filled up in storms. This construction has been so effective that the water of the estuary rises and falls practically to a maximum degree and thus has the greatest scouring effect. This change came about more or less gradually. It seems quite sufficient to explain the poor entrance of salmon into the estuary, of which complaint is made. If there were a good bar, the steady outflowing current would direct the salmon in. If the estuary were deeper or if the fish were smaller and swam nearer the surface, they would lead along a contour line that would take them into the estuary. Of course, if as smolts they had learned the way on swimming out of the estuary, the salmon would have no difficulty in entering the estuary as it now is, since there is always plenty of water for salmon to swim in, even for the largest known. Forty-pounders occur and have been taken, at least in the Cheticamp.

The matter is important for practical action. To give Margaree anglers better fishing and to give Moser anglers larger fish, changes must be made in the mouths of the estuaries of these rivers, if the above interpretation of the facts is correct. The necessary changes would not be difficult to make, but other human interests might prevent their being made.

It would seem that a tight gate at the narrow mouth of the Margaree estuary would need only to be closed during the early summer season of salmon abundance on the coast in order to furnish a steady outward current over it to direct the salmon riverward. During the rest of the year it would be always open to permit the tidal scouring of the channel required for navigation. Even during the salmon season, it need not prevent navigation, but could be opened as required for entrance and exit of vessels.

For Moser River, it happens that the public wharf, at which vessels land, is at the very mouth of the estuary at Necum Teuch. There might be no serious interference with navigation if a dam or bar were built just inside the wharf in order to provide a steady outward current to direct large salmon

and small salmon alike to the river mouth. For such boating as there is in the estuary it might even be an advantage to keep the water steadily at quite a high level. For both rivers, the proposed action would affect the net fishing in ways that are not as yet very evident, but in making salmon entrance easier and earlier it would make the net fishing less profitable. Presumably this loss would be more than offset by better rod fishing, which can be more valuable.

In conclusion, it should be stated that practically and scientifically we cannot afford to ignore the facts. It is for every body to judge whether the conception of a homing mechanism or that of a wandering mechanism is more satisfactory for handling the facts effectively. I can only affirm that I have failed to find the former useful, except to the small degree that I mention, but have found the latter to be so in spite of its manifest complexity.

ROLE OF BRITISH COLUMBIA IN THE NORTH AMERICAN RECREATION AND WILDLIFE PICTURE

SUMMARY

DR. FERRIS NEAVE
Principal Scientist, Pacific Biological Station

The broad factors which determine British Columbia's place in the North American recreation and wildlife picture have been stated very clearly in the contribution supplied by the British Columbia Parks and Recreation Division. They are:

1. The quantity and quality of the resources (the "potential").
2. The market demand for the resources.
3. The availability and the marketing policies connected with similar or alternative resources elsewhere.
4. The availability of resources and the marketing policies in B.C.

Some of the aspects of these determining factors will be dealt with more appropriately in the second part of this session.

QUALITY AND QUANTITY OF BRITISH COLUMBIA'S RECREATIONAL AND WILDLIFE RESOURCES

In assessing the British Columbia potential we should attempt a serious and objective appraisal. As one contributor remarks, the sun shines in many other places, too. In point of fact, British Columbia does not possess the warmest beaches, the highest mountains, the largest lakes and glaciers in North America, nor does it hold a monopoly on scenic beauty. The boundaries of the province are only natural in part and in other parts are not recognized by fauna, flora, geology or weather. In general, the lands and fresh waters of British Columbia are not remarkable for the heaviness of their population of wildlife and fish.

Nevertheless, after these initial manifestations of modesty, we can fairly claim that the recreational and wildlife potential is great. This potential stems of course from geographic and climatic features. Within the political boundaries with which we define our realm there are many "countries" which can be defined in other ways.

There are varying resources which are associated with the fact that British Columbia covers more than 11 degrees of latitude—or 800 miles in a north-south direction. There are the much greater differences which are associated with distance from the sea, with precipitation, with the presence and orientation of mountain ranges. We have the striking contrasts between the coastal rain forests and the arid areas of the Interior and, in smaller space, between valley bottoms and mountain tops. Cowan and Munro in their review of the bird fauna have recognized 13 different

Paper presented to the Fifth British Columbia Natural Resources Conference by Dr. Ferris Neave, Principal Scientist, Pacific Biological Station, Nanaimo, B.C., on February 27th, 1952.

types of land area, i.e., types of country having special characteristics of fauna or flora. These differences are reflected, at least to a degree, in variety of recreational opportunity. One contributor expresses the situation in five words: "You are blessed by geography."

With respect to game and fish, we have already indicated that British Columbia does not produce such heavy crops of some species as do lands with richer soils and food supplies. It does, however, produce a great many of the most eagerly sought species—both of fish and of game—in all the temperate regions of North America—and in greater numbers than these occur in most other places. In the big game category especially, a comparison with other places gives British Columbia an impressive position.

Without any reluctance, we are forced to conclude that, relative to most parts of North America, British Columbia has a very high potential in respect to its resources of outdoor recreation and wildlife.

We have undoubtedly gone a long way around to reach an obvious conclusion. However, the potential does not in itself determine British Columbia's place in the North American picture. Moreover the resources are not likely to remain at exactly the same level. The resources we are talking about are of different kinds and have different abilities to survive.

Many forms of recreation do not destroy the raw materials they require—e.g., swimming, skiing, photography, climbing, wildlife observation and contemplation of scenic beauty. These occupations may be threatened by other forms of land and water use—industrialization, deforestation, mining. Hunting and fishing are in a special category because they are not only very susceptible to such external changes in environment but are also quite capable of themselves killing the goose that lays the golden eggs. For the moment we need only remind ourselves that the British Columbia resources are large by comparative standards but that they may be subject to shrinkage.

Market Demand

Very impressive figures can be quoted which attempt to show the scope of the demand for recreational and wildlife resources. These figures generally relate to the number of people doing certain things or the amounts paid annually for the equipment, travel or accommodation. It may justly be said that such figures do not measure the *demand.* They measure certain by-products of the demand—or the extent to which particular people are able to satisfy their material wants—or it may be that they illustrate the peculiar ways in which human beings respond to certain stimuli. The demand itself is something different, for which no measuring scale has been devised. Nevertheless these figures are used extensively in the absence of better measurements. It is impressive to be told on good authority that over 130,000,000 people visited U.S. National and State Parks in 1949 or that the annual North American expenditure on recreation is some 12 to 15 billion dollars, i.e., at least 4 times the value of all manufactured products produced in Canada and more than the total Canadian expenditure for consumer goods and services.

The North American recreation resource market at present consists mainly of about 50,000,000 families supported by wages or salaries averaging about $3,000 in 1949.

It is interesting to note that the resource most in demand, according to a sample survey, is scenic beauty, a commodity which is cheap, plentiful and relatively indestructible in British Columbia.

Concerning game, the number of deer-hunters alone in certain individual states runs into the hundreds of thousands. The annual U.S. expenditure on sport firearms, ammunition and fishing tackle is said to be something like $60,000,000.

While such figures do not measure the demand for recreation and wildlife resources, they indicate that it is active, if not desperate.

Resources Elsewhere

One contributor remarks: "If British Columbia's place in the North American recreation picture is to be clearly seen, it is necessary that we discover how our competitors package and market their goods and how successful their methods may be." Another says that British Columbia's resources should not be regarded as a substitute for American Federal Parks. Evidently it is possible to regard these other sources of recreation either as competitors for business or as valuable supporters relieving the pressure on our own supplies. Both statements however, while representing quite different viewpoints, recognize that the demand for British Columbia resources is related to the attractiveness of alternative sources of supply.

Referring again to the fund of information contained in the Parks and Recreation Division's contribution, we learn that the U.S. National Parks Service administers 181 parks and sites comprising 23,000,000 acres and spends annually more than $1.00 per acre in efforts to make recreational facilities avilable to the public, by roads, trails, camp grounds, etc.

A much greater area, 180,000,000 acres, is administered by the U.S. Forest Service. Recreation is not the primary purpose on these lands but is recognized as one of the major considerations and is promoted by expenditures, for recreational development alone, of nearly $20,000,000 in 1949.

State Parks cover more than four and a half million acres and average expenditure on administration was over $7.00 per acre in 1949. The attendance totalled 108,000,000 visitors.

Recreation also takes place of course outside the boundaries of national or state parks or national forests. To draw an example from the Game field, it is reported that Wisconsin had 275,000 deer-hunters in 1950; Oregon 173,000. British Columbia about 50,000.

Evidently a colossal job of catering is being done elsewhere which is heading off the customers from, or cushioning the attack on, British Columbia.

The force and direction of the impact from the rest of North America on British Columbia can be controlled by administrative policy and action. This is a subject which belongs properly to the second section of this

meeting. But we cannot overlook the fact that the quantity and availability of resources elsewhere will play an important part in determining British Columbia's role in the general picture.

Availability and Use of British Columbia's Recreation and Wildlife Resources

Judging by the kind of figures we have been discussing, British Columbia is not at present occupying a prominent place in the North American recreational picture. The visitors to her National Parks are relatively few, not only by United States standards but also by the standards of such sister provinces as Ontario, Manitoba and Alberta. Her deer-hunters and anglers are a small group in comparison with the armies quartered elsewhere. Many of her scenic attractions are almost unknown in spite of the fact that "no Canadian province nor any American state boasts provincial or state park acreage approaching that of this province either on the basis of acres per capita, ratio of parks to land area or total area of parks." "In the North American picture, British Columbia appears to occupy the place of a merchant with a large and potentially saleable inventory but comparatively few sales."

Up to this point, then, and speaking in comparative terms, it seems (1) that British Columbia has a very high recreation and wildlife potential which, however, in the case of some resources is far from unlimited; (2) that there is a large and increasing demand for the kinds of resources which British Columbia possesses; (3) that at the present time this demand is being largely met elsewhere—or at least it is not being met in British Columbia. From the North American viewpoint, therefore, British Columbia is at the moment suffering or enjoying a rather inconspicuous place.

The title of this section, however, is not "the momentary place of British Columbia . . ." but the "*role* of British Columbia . . ." It may be that she has not yet really begun to play her role.

Concerning the role of British Columbia, i.e., the place which she will or should assume, there is some divergence of views. Let our contributors speak for themselves.

"In the North American recreation picture British Columbia, with 116,000 visitors to its National Parks and 300,000 visitors to areas administered as Provincial Parks, with a tourist income of 60 million dollars from a Continental vacation expenditure of about 14 billion, occupies the place of the undecided youngster bobbing about in the back row, unsure whether he wants to be in the picture or not. Dazzled, perhaps, by million dollar enterprises he is unable to see the 12 billion dollar enterprise which is poised on this threshold.

"In the future North American picture British Columbia may occupy a prosperous, prominent place. Competition for such places is keen, however, and it may be that British Columbia will prefer to remain in the smaller markets.

"With no more than 5,000,000 to 8,000,000 acres of potentially arable land, with only 75,000,000 acres capable of producing commercial timber, with 45,000,000 acres of unproductive alpine soils and more than

100,000,000 acres of alpine tundra, muskeg and grey wooded soil of the north country, British Columbia may well give thought to the sustenance of the future; may well take stock of all our resources; may well seek a place in the North American recreation and wildlife picture.

"British Columbia's recreational resources ought primarily to serve British Columbia people. They are too scarce or 'fragile' to contribute much to North American recreation. The North American aspect is a secondary use, to be encouraged only where the resource concerned is of a lasting nature.

"Shall we advertise to the four corners of the globe that British Columbia is a sportsman's Mecca with an abundance of fish and game? Definitely not. Far too much of this sort of thing has been done already. This province may have ample game to supply the needs of its own sportsmen (which we doubt) but is there enough to supply the rest of North America with ideal hunting and fishing?"

From our U.S. contributor: "Don't let us come into your country and degrade sportsmanship or damage your wilderness resources. I have been told that you have already established aircraft regulations to safeguard sport and wilderness. Such a move helps us to similar action south of your border."

There are real differences in these points of view, but the differences are exaggerated by my unfair manner of putting them alongside each other. Not all refer to the same sort of resource. Nearly all contributors draw a distinction between hunting and fishing and the exploitation of less fragile resources. There is, in fact, a measure of agreement which is perhaps rather surprising in view of the different professed interests of these various organizations.

All recognize the legitimacy of some expansion in the availability of non-lethal forms of resource. Opinions here vary from those who consider that developments in this field are a legitimate secondary consideration in a general policy of British Columbia for British Columbians to those who see the possibility of an immense contribution to North American welfare and vast business benefits without sacrificing our own pleasures or mortgaging the future. The latter point of view is most fully expressed by the Parks services, both Provincial and National. These organizations deal to a very large extent with non-destructive use of resources, they have good control over their resources and they have before them examples of successful developments in other areas.

There is, however, unanimous recognition, not only by Parks services but by Fish and Game enthusiasts too, of the great and growing requirements of those who do not themselves fish or hunt. There is a strong feeling that under wise management the resources available to the hiker, the nature lover, the bird watcher, skier or photographer can be preserved and increased, and that these forms of recreation deserve every encouragement. There is a general negative to cheap or short-term exploitation of resources. As one contributor puts it, we want no California hamburger stands nor any Little Bits of Old pseudo-England.

The game picture is rather different. There is general agreement

that British Columbia has a job of work to do here. There is little confidence that under existing conditions the province can supply the North American demand. Two ideas seem to be paramount. First—Wildlife must be preserved intact in some areas as a continuing source of enjoyment to nature lovers and as a trust fund for the future. Second—Game stocks should at least provide a continuing resource for resident hunters and fishermen—and for an increasing population of these.

Concern for the future is a main feature of the pages devoted to the role of game. National parks are seen as a vitally necessary part of the long-term programme. Emphasis is also laid on *management*. There is a widespread feeling that more positive measures should be taken to increase game supplies than the mere application of bag limits and closed seasons, that *habitat improvement* offers a major opportunity for maintaining resources which at the present time are not too plentifully supplied by nature and are subject to pressures by industrialization and hunting. Recognition is given to the progressive strides made by British Columbia in management work in recent years, but it is felt that this is merely a beginning. "As a conservative estimate, half the states in the Union and at least one province are making contributions to the future of their wildlife by habitat manipulation; or better, land acquisition for wildlife upon which vegetation is modified to benefit wildlife. Action such as this is reasonably permanent and strikes at the root of wildlife problems. All other management procedures are of secondary importance to working with wildlife through environment. We will not have a mature management programme until we follow the lead of our progressive neighbours. And without a mature attitude we cannot realize the unique potential of this province for all kinds of wildlife use."

The scientific conservationist, far from being considered a taxpayer's burden or an impractical crackpot, is evidently respected as the man of the future. We must hope that he can live up to the expectations of his public.

While I have found few rash predictions in these essays as to the position which British Columbia will in fact occupy in future yars, and there is also some diversity of opinion as to the position which she *should* occupy, there is a chorus of agreement as to the necessity for certain kinds of stocktaking and planning, if she is to play a worthy role of any kind.

One of these needs relates to the *evaluation* of the kinds of resources we have been discussing. We have already referred to the difficulty of assigning absolute values in terms of numbers of people or dollars. Yet we are more and more often called on to make a choice between a recreational or wildlife resource and some other legitimate human activity or project, or even between different kinds of wildlife resources themselves. In some cases we might find, if we knew more, that the conflict is imaginary and that both claims can be reconciled. In other cases a compromise might be making the worst of two worlds. The necessity for decisions remains.

In setting up standards for these decisions, contributors to this section are emphatic in saying that numbers of people and financial returns do not accurately measure the value of this kind of resource, any more than they measure the current demand for it.

"There are many values involved, only a few of which can be ex-

pressed in the usual and often meaningless astronomical figures used in resource evaluation. Of necessity some such figures will be used but 'it is a shallow man who has a price for everything' and the same is true of nations, or provinces.

"The proximity of resources to large populations is important.

"Aesthetic aspects ought not to be neglected.

"As our population increases the need will become greater and unless every possible step is taken to preserve our wildlife for the refreshment of our citizens, we shall gradually lose this unequalled source of national vigour.

"Recreation stands apart. We can measure our material needs in board feet, bushels, tons. What measure have we devised to compute the value of recreation? True, many who profit by it financially measure it in dollars, in local or provincial income. *But they are not measuring the value of recreation.* They measure a *by-product* of an intangible resource that can only be experienced, not measured."

These ideas are no doubt difficult to translate into terms of practical policy and administration. Some contributors feel that this question of evaluation puts wildlife especially at a permanent disadvantage in comparing the merits of different kinds of resources. There is danger, as one author ably expresses it, that "wildlife will always be relegated to the poorest nipple". There is a general plea, however, that these intangibles should be taken into very serious consideration by administrators.

Put into rather different terms, the question of values is really the question of *land use* (and water use). There is recognition of the fact that British Columbia's 234,000,000 acres are capable of producing much wealth, both spiritual and temporal. A resource is not a resource unless it is usable, whether by one man or by a million. The acreage, although vast, is not unlimited. It should be used in some way, whether as the centre of an industry or as a spiritual haven for refugees from a tough world. In many cases alternative uses are possible.

Our several authors have stressed their belief that recreational and wildlife resources are entitled to a respected place in deliberations as to the proper use of land. With one accord, however, they emphasize their concern with a broader objective than the championing of the cause of some particular resource. Unanimously they ask for broad planning with respect to land use, realizing that their own special interests will certainly suffer at some points, but convinced that the best values cannot be extracted from our resources by the emergency treatment of each conflict as it arises. This, I think, is the cardinal point which emerges from these thoughtful papers submitted by groups with different professed interests. It calls for administrators of imagination and courage. It calls for government machinery, about which we are shortly to hear. It calls especially for co-operative planning in which all groups can be assured of a sympathetic hearing.

The role of British Columbia in the North American recreation and wildlife picture will emerge from this background of the planned use of our land.

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CHROMATOGRAPHIC SEPARATION AND MICROBIOLOGICAL ASSAY OF INDIGENOUS AND ADDED COBALAMINS IN CRUDE ANIMAL PROTEIN MATERIALS[1]

By H. L. A. Tarr[2]

ABSTRACT

Identical growth, as measured turbidimetrically, resulted when *Lactobacillus leichmannii* was cultured in a previously sterilized assay medium to which vitamin B_{12} (cyano-cobalamin) or vitamin B_{12a} or B_{12b} (hydroxo-cobalamin) had been added aseptically, providing that the inoculum and incubation conditions were carefully controlled. From 91 to 107% of the total cobalamins in herring meal as indicated by direct assay were recovered after chromatographic separation on KH_2PO_4-treated filter paper strips, elution, and assay. When 500 mμgm. of cyano- or hydroxo-cobalamin was added per gram of herring meal and the aqueous suspensions were autoclaved at 120°C. for five minutes direct assay yielded 96 to 111% of the expected amounts, and of this 81 to 99% was recovered after chromatographic separation. When 10% aqueous herring meal suspensions were autoclaved at pH 7.0 with 0, 1, 10, and 100 μgm. of potassium cyanide per ml. the following respective ratios of hydroxo- to cyano-cobalamin were found: 95:5; 90:10; 64:36, and 50:50. No important difference in the total cobalamin content of herring meal was found as a result of cyanide treatment, but autoclaving with 0.5 mgm. per ml. of mercaptosuccinic acid caused a fictitiously high recovery. Qualitative chromatography of raw and autoclaved fish kidney and beef liver extracts indicated that hydroxo-cobalamin, or forms of the vitamin with similar chromatographic properties, account for at least 95% of their total cobalamin content. The following results were obtained by direct assay: sockeye salmon kidney 3664, chum salmon kidney 2110, and beef liver 1580 mμgm. of total apparent cobalamin per gram wet weight, of which 71, 91, and 55% respectively was recovered following chromatographic separation, elution, and assay.

INTRODUCTION

Since the discovery that vitamin B_{12} is a cyano cobalt co-ordination complex (cyano-cobalamin) (3), and that a number of related cobalamins which cause very variable response in microbiological assay procedures (13, 14) can be prepared, an assay method which will give identical recovery with the different forms of the vitamin has been sought. Vitamin B_{12} and vitamin B_{12a} (hydroxo-cobalamin) have been the only readily available forms and hence have been most extensively investigated. Vitamin B_{12a}, obtained by catalytic reduction of vitamin B_{12}, and vitamin B_{12b} which has been prepared from *Streptomyces* fermentation liquors, are apparently chemically indistinguishable (12, 13, 14).

[1] *Manuscript received May 27, 1952.*
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[2] *Fisheries Research Board of Canada, Pacific Fisheries Experimental Station.*

Remarkable confusion exists regarding the response of the *Lactobacilli*, currently employed in vitamin B_{12} microbiological assay procedures, to the various cobalamins. Aseptic addition of cyano- and hydroxo-cobalamin to separately sterilized assay media has been reported by some workers to occasion identical growth response of assay organisms (11, 12, 15), while others have reported that cyano-cobalamin occasions lower growth response than does hydroxo-cobalamin under these conditions (4). Sterilization of different cobalamins in media containing reducing agents has been variously reported as resulting in identical growth of assay bacteria (6, 11) and as causing a much lower growth response to hydroxo- than to cyano-cobalamin (13). Reducing substances evidently exert a very variable effect on the different cobalamins depending on the conditions of exposure to them. Thus they have been reported to have a direct destructive action on cyano-cobalamin (16) and also to form adducts with this cobalamin which are more active microbiologically (4, 25).

Sterilization of cyano- and hydroxo-cobalamins in media containing cyanide but no reducing agent has been stated to result in similar growth of assay organisms (6, 22). However, the absence of a reducing agent results in comparatively slow growth of the assay bacteria; hence only titrimetric procedures have been used in methods employing cyanide. Autoclaving vitamin B_{12}-containing materials with sodium metabisulphite appears to stabilize the vitamin so that it will withstand prolonged autoclaving over a wide pH range without altering its ability to stimulate growth of *L. leichmannii* (17). Vitamin B_{12}-requiring mutants of *Escherichia coli* have been employed as assay organisms either in cup-plate procedure (1, 9), or in a continually shaken liquid medium (5). These mutants do not respond to deoxypentosides but are somewhat sensitive to methionine and are extremely sensitive to substances which appear to be very similar to vitamin B_{12} and which occur in certain natural materials (8).

There is at present no acceptable standard method for the microbiological assay of different cobalamins, and there have been few attempts to compare results obtained with different methods as applied to crude natural materials. Hence it is not surprising that microbiological assays of crude materials such as fermentation liquors (24), fishery products (23), and animal tissues (19, 20) for vitamin B_{12} have not yielded very reproducible results. The occurrence, in these materials, of hydroxo-cobalamin (23, 24, 25, 26), of deoxypentosides (15), of other vitamin B_{12}-active substances (8, 9, 29), and even of antibiotics (8, 24) may cause either fictitiously high or low results.

The present work was carried out to establish conditions under which identical microbiological assay results could be obtained with cyano- and hydroxo-cobalamins, to determine how much of the total cobalamin content of certain crude animal protein materials could be recovered after concentration by chromatographic separation using filter paper technique, and finally to ascertain the stability of added cobalamins during the autoclaving procedure used in releasing the indigenous cobalamins present in these natural materials. At the time this work was carried out some of the methods referred to above had

not been published and it is realized that certain of them may prove equally reliable and possibly more simple in application than the technique to be described.

EXPERIMENTAL

Materials and Methods

Since there appears to be considerable similarity in the vitamin B_{12} content of commercial fish meals prepared from herring (23) (*Clupea pallasii*), a single sample of a commercial November 1950 flame-dried meal was arbitrarily selected for use in the experiments to be described. It was ground in a Wiley mill so that all particles passed through a 40-mesh sieve and stored at − 4° C. in the dark until required. The chum salmon (*Oncorhynchus keta*) kidney used was a representative sample taken from 50 lb. of material collected during November 1950 and stored at − 4° C. The sockeye salmon (*Oncorhynchus nerka*) kidney was from a sample which had been stored for about three years at − 18° C. and had been used in former work (27). The beef liver was a small sample purchased locally. Crystalline vitamin B_{12} and vitamin B_{12a} were kindly supplied by Dr. H. B. Woodruff of Merck and Co., Rahway, N.J., and crystalline vitamin B_{12b} by Dr. H. G. Luther of Chas. Pfizer and Co., Brooklyn, New York.

In all procedures care was taken to avoid exposure of the vitamin B_{12} solutions to bright light, all operations being conducted in subdued light or, whenever possible, in the dark. The vitamin standard solutions were prepared and stored in glass stoppered volumetric flasks at 0° C. in the dark since it has been found that, under these conditions, they do not appear to lose their potency appreciably for months.

Microbiological Assay Procedure

The medium of Skeggs, Nepple, Valentik, Huff, and Wright was employed without added ribonucleic acid or nucleotide (21), and with *Lactobacillus leichmannii* A.T.C.C. 4797 as assay organism. Considerable difficulty was experienced in obtaining conditions under which identical response of the assay organism to both cyano- and hydroxo-cobalamin could be obtained with this medium. This may have been due partly to the different susceptibilities of the cobalamins to reducing agents such as ascorbic acid (16, 28). Though in a brief earlier report of this work (25) it was stated that the use of ascorbic acid in the medium resulted in an apparent preferential destruction of cyano-cobalamin, it has been found subsequently that ascorbic acid (1 mgm. per ml. of double strength medium), mercaptosuccinic acid, or thioglycolic acid (0.5 mgm. per ml. of double strength medium) all give satisfactory results provided the assay conditions are such that rapid growth of the assay organism results. In the medium used cyano-cobalamin is much more unstable than hydroxo-cobalamin, and in several experiments it was found that the former is inactivated much more rapidly than the latter in the uninoculated assay medium in the presence of added reducing agent. Possibly rapid growth of the assay organism is desirable because under such conditions the cobalamins may not be affected

appreciably by undue exposure to reducing agents. It is not clear whether the recently reported ability of *L. leichmannii* cells to bind small amounts of the vitamin quite firmly (7) has any bearing on the necessity for obtaining rapid growth in order to obtain identical results with different cobalamins. The vigorous inoculum used (*vide infra*) may contain sufficient viable cells to bind the vitamin present rendering it unsusceptible to reducing agents, and it may later become available to other cells. The following assay procedure was found satisfactory and yields identical results with both forms of cobalamin.

The reducing agent was added to the freshly prepared double strength medium (final pH 6.5) which was automatically dispensed in 2-ml. quantities into 18 × 150-mm. tubes contained in copper boxes. After dispensing the required quantities of water the tubes were sterlilized for five minutes at 120° C. and promptly cooled. Controls were prepared with both cyano- and hydroxo-cobalamins by adding aseptically from 0.1 to 2.0 ml. of their sterile solutions containing 0.2 mμgm. per ml., four replicates being used at each of seven levels. The separately sterilized aqueous extracts of the various protein materials (*vide infra*) were assayed in from 1:5000 to 1:20,000 dilution using four replicates at four levels. *L. leichmannii* was transferred daily at 37° C. in the assay medium containing 0.1 mμgm. (and in some experiments 0.2 mμgm.) of cyano-cobalamin per milliliter, the cultures being incubated 16-18 hr. at 37° C. If it was not convenient to use these cultures directly 1 ml. was transferred to 7 ml. of the same medium and incubated five to six hours at 37° C. Individual assay tubes were inoculated with 0.1 ml. of a 1:100 dilution of this culture prepared in assay medium minus cobalamin, shaken gently, and incubated 18 hr. at 37° C. Great care was taken to avoid chilling of the assay organism at any stage since this may hinder rapid growth. Identical response of the organism to both cobalamins resulted with this technique involving aseptic addition of the cobalamin-containing solutions to the sterile medium, while their sterilization in the assay medium containing a reducing agent (mercaptosuccinic acid) enhanced the response to cyano-cobalamin but occasioned a decreased response to hydroxo-cobalamin (Fig. 1). All assays were controlled with both cyano- and hydroxo-cobalamin.

Chromatographic Separation of the Cobalamins

The method of Woodruff and Foster which separates cyano- and hydroxy-cobalamin from each other, from vitamin B_{12}-active deoxypentosides (30), and also from certain slow-moving factors (27, 30) was used. All operations were carried out in subdued light, the filter paper strips being developed for 48 hr. at 37°C. The position of the cobalamins on one of the chromatograms was located by placing it on an agar medium inoculated with a vitamin B_{12}-requiring mutant of *Escherichia coli* (24) in order to locate them on the remaining chromatograms for elution and subsequent assay.

Experiment 1

One-gram samples of herring meal were suspended in 9.0 ml. of water, or mercaptosuccinic acid solution (final concentration 0.5 mgm. per ml.), with

and without 500 mμgm. of added vitamin B_{12}, B_{12a}, or B_{12b} per sample (Table II). The samples (pH 6.5) were gently mixed, autoclaved for five minutes at 120°C., promptly cooled in the dark, centrifuged several minutes, and stored in rubber stoppered centrifuge tubes at 0°C. in the dark. Three chromatograms were prepared with each extract (0.01, 0.02, or 0.05 ml.) and direct microbiological assays for total cobalamin content were carried out using the extracts on the day of preparation and after three days at 0°C. Duplicate chromatograms were prepared with 5 mμgm. each of vitamin B_{12} and B_{12a} as qualitative and quantitative controls. The results obtained on qualitative development of the chromatograms are given in Table I. The findings for crystalline cyano- and hydroxo-cobalamin are similar to those originally reported (30) and which have been verified in this laboratory (24, 27). The aqueous extracts of herring meal showed much more pronounced growth zones corresponding to hydroxo-cobalamin than to cyano-cobalamin, and this qualitative picture was not appreciably altered in samples to which measured amounts of these cobalamins were added. In the samples heated in the presence of mercaptosuccinic acid large growth zones developed which were slightly further from the point of application than those occupied by hydroxo-cobalamin. This indicated the formation of a mercaptosuccinic acid adduct of vitamin B_{12} similar to that formed in aqueous solutions of the crystalline vitamin (4).

The quantitative data given in Table II show good agreement in the results of duplicate assays of both crude extracts and eluates from chromatograms. Satisfactory recovery of added cyano- and hydroxo-cobalamins from the autoclaved water suspensions of the fish meal indicated that the heating did not cause any serious destruction of the vitamins. This result was further substantiated by assay of the chromatographically separated cobalamins.

A considerably higher total vitamin B_{12} content was indicated when the meal was autoclaved in mercaptosuccinic acid containing solution. That this was due to the formation of a more microbiologically active adduct of the vitamin is suggested from a recent report (4), from the results of qualitative chromatographic separation reported above, and from the unreasonably high apparent recovery in the sample containing added cyano-cobalamin. It has been found in the present work that autoclaving crystalline cyano-cobalamin in the culture medium in the presence of mercaptosuccinic acid results in a response which is greatly in excess of that obtained from its aseptic addition under identical conditions (Fig. 1). The circumstance that the mercaptosuccinic acid adduct which is formed may be rather unstable is indicated from the much lower, and apparently more normal, recoveries found when the cobalamin was separated chromatographically and assayed. It is possible that a partial transition of the thio-adduct to a microbiologically less active form occurs during chromatographic separation. Cyano-cobalamin yields 10% of hydroxo-cobalamin when chromatographed under these conditions (30). There was good recovery of added hydroxo-cobalamin in mercaptosuccinic acid treated samples. Since crystalline hydroxo-cobalamin is apparently rather unstable when autoclaved in the assay medium containing mercaptosuccinic acid (Fig. 1) these results

TABLE I

QUALITATIVE DISTRIBUTION OF COBALAMINS ON CHROMATOGRAMS OF SAMPLES IN EXPERIMENT 1

Product chromatographed	Relative size of growth zones and average distance of migration of the cobalamins from the point of application (cm.)	
	Zone corresponding to cyano-cobalamin	Zone corresponding to hydroxo-cobalamin
5 mμgm. of vitamin B_{12}	Large, 21	Small, 8.0
5 " " " B_{12a}	None	Large, 7.5
0.10 ml. of aqueous extract; no added vitamin	Small, 20	Large, 7.5
0.05 " " " " ; vitamin B_{12} added	Small, 24	Large, 8.0
0.05 " " " " ; " B_{12a} "	Small, 25	Large, 8.0
0.10 " " mercaptosuccinic acid extract; no added vitamin	None	Large, 10.0*
0.05 " " " " " ; vitamin B_{12} added	None	Large, 10.0*
0.05 " " " " " ; " B_{12a} "	None	Large, 8.0

* *The slightly increased rate of migration of the vitamin in these preparations suggests that a mercaptosuccinic adduct (4) was present.*

TABLE II

VITAMIN B_{12} CONTENT OF HERRING MEAL WITH AND WITHOUT ADDED COBALAMINS AS DETERMINED AFTER AUTOCLAVING AQUEOUS SUSPENSIONS OR SUSPENSIONS CONTAINING 0.5 MGM. PER ML. OF MERCAPTOSUCCINIC ACID

Material assayed	Mμgm. of vitamin B_{12} activity per gram of meal							
	Extracts assayed directly				Cobalamins separated chromatographically, eluted, and assayed			
	1*	2*	Av.	% Recovery**	1	2	Av.	% Recovery***
Water extracts								
No added vitamin	360	361	361		375	341	358	99
500 mμgm. of vitamin B_{12} added	932	970	951	111	760	775	768	81
500 " " " B_{12a} "	840	808	824	96	731	750	741	99
500 " " " B_{12b} "	845	813	829	96				
Mercaptosuccinic acid extracts								
No added vitamin	515	486	501		361	409	385	77
500 mμgm. of vitamin B_{12} added	1550	1523	1537	153	1073	1106	1090	71
500 " " " B_{12a} "	1115	945	1030	103	900	916	908	88
500 " " " B_{12b} "	1095	984	1040	104				
5 mμgm. vitamin B_{12} chromatographed					4.20 mμgm. recovered = 84%			
5 " " B_{12a} "					5.23 " " = 104%			

* *Assay values under (1) were obtained on the day of preparation and under (2) after three days at 0°C.*

** *Based on the calculated values obtained by adding 500 to the average assay values obtained for the extracts without added cobalamin (861 for the watery extracts and 1001 for the mercaptosuccinic extracts respectively).*

*** *Calculated as per cent of the average values obtained by assaying the extracts directly.*

are not easy to explain. It is possible that certain substances in the crude fish meal suspensions protected the hydroxo-cobalamin.

That the chromatographic procedure is accompanied by no appreciable loss of the cobalamins is indicated from the excellent recoveries obtained with the 5-mμgm. portions of vitamin B_{12} and B_{12a} both in this and in subsequent experiments.

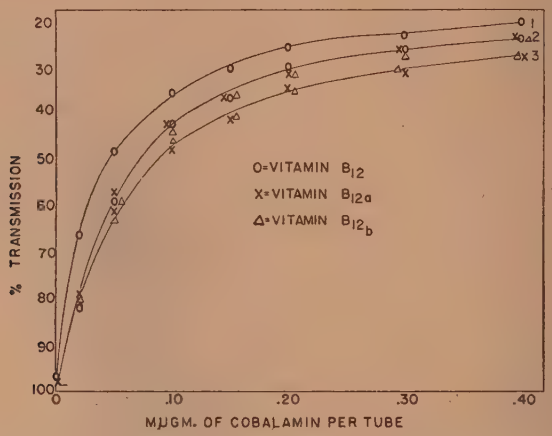

FIG. 1. Response of *L. leichmannii* to cyano- and hydroxo-cobalamins. 1 and 3 = cobalamins autoclaved in the medium for five minutes at 120°C. 2 = cobalamins added aseptically to the previously sterilized assay medium.

Experiment 2

Cyanide treatment of crystalline hydroxo-cobalamin and of certain other cobalamins yields cyano-cobalamin (13), though similar treatment of crude *Streptomyces* fermentation liquors at pH 5.5 resulted in only partial conversion of hydroxo- to cyano-cobalamin (24). The effect of cyanide on the recovery of indigenous and of added cobalamins in fish meal, as well as its influence on the ratio of hydroxo- to cyano-cobalamin in the treated meal, was investigated. One-gram samples of fish meal, with and without added cobalamins and potassium cyanide, were treated similarly to these in Experiment 1, except that the reaction of the suspensions was adjusted to pH 7.0 prior to autoclaving them. The extracts were assayed microbiologically and portions were chromatographed (Table III) shortly after preparation. The samples were assayed again after four days' storage at 0°C.

Qualitative determinations of cyano- and hydroxo-cobalamins in the treated meal extracts (Table III) showed that not all the hydroxo-cobalamin was changed to cyano-cobalamin though the size of the growth zones corresponding to cyano-cobalamin increased in the samples treated with 10 to 100 μgm. of potassium cyanide per ml. The quantitative results (Table IV) confirm and extend this finding. Cyanide treatment had no important effect on the results found by direct microbiological assay, and good recoveries of added cobalamins

TABLE III

QUALITATIVE DISTRIBUTION OF COBALAMINS ON CHROMATOGRAMS OF SAMPLES IN EXPERIMENT 2

Product chromatographed	Relative size of growth zones and average distance of migration of the cobalamins from the point of application (cm.)	
	Zone corresponding to cyano-cobalamin	Zone corresponding to hydroxo-cobalamin
5 mμgm. of vitamin B_{12}	Large, 19	Small, 7
5 " " " B_{12a}	None	Large, 8
0.1 ml. of aqueous extract	Small, 15	Large, 5
0.1 " " " " , 1 μgm. KCN per ml.	Small, 15	Large, 5
0.1 " " " " , 10 μgm. " " "	Large, 14	Moderate, 4
0.1 " " " " , 100 μgm. " " "	Large, 14	Moderate, 5
0.05 " " " " , containing added vit. B_{12}, 100 μgm. KCN per ml.	Large, 19	Moderate, 5
0.05 " " " " containing added vit. B_{12a}, 100 μgm. KCN per ml.	Large, 20	Moderate, 7

TABLE IV

VITAMIN B_{12} CONTENT OF HERRING MEAL, WITH AND WITHOUT ADDED CYANO- AND HYDROXO-COBALAMINS, AS INFLUENCED BY CYANIDE TREATMENT

Product chromatographed	Mμgm. of vitamin B_{12}-activity per gram									
	Extracts assayed directly				Cobalamins separated chromatographically, eluted, and assayed					
	1††	2††	Av.	% Recov.†	B_{12}+ B_{12a}*	% Recov.**	B_{12}***	B_{12a}***	Sum	% Recov.
Suspension untreated	390	367	379		346	91	21(5)	382(95)	403	107
Suspension containing 1 μgm./ml. of KCN	374	319	352		346	98	35(10)	327(90)	362	105
" " 10 μgm./ml. " "	348	338	343		311	91	150(36)	272(64)	422	123
" " 100 μgm./ml. " "	394	351	375		365	98	183(50)	183(50)	366	98
" " added vitamin B_{12} + 100 μgm./ml. of KCN	892	740	816	93	784	96	462(64)	264(36)	726	89
" " added vitamin B_{12a} + 100 μgm./ml. of KCN	793	740	767	88	680	89	416(61)	266(39)	682	89
5 mμgm. vitamin B_{12} chromatographed					5.50 mμgm. recovered = 110%					
5 " " B_{12a} "					5.16 " " = 103%					

* *Both the vitamin B_{12} and vitamin B_{12a} zones were eluted together and assayed.*

** *Expressed as per cent of the average cobalamin content as found by direct assay.*

*** *The zones were eluted and assayed separately, the figures in brackets represent the per cent of each cobalamin with respect to the total amount.*

† *Calculated on the basis of an expected total of 375 (indigenous) + 500 (added) cobalamin = 875 mμgm.*

†† *Assay values under (1) were obtained on the day of preparation and under (2) after five days at 0°C.*

were obtained. Simultaneous elution of both cyano- and hydroxo-cobalamin zones from one filter paper chromatogram followed by microbiological assay, showed that between 89 and 98% (average 94%) of the vitamin B_{12} activity found by direct assay was recoverable after such treatment. Assay of each zone separately using the remaining chromatogram indicated that the untreated aqueous suspension contained 95% of hydroxo-cobalamin. Cyanide treatment of the fish meal suspensions caused only partial conversion of hydroxo- to cyano-cobalamin even when the concentration of potassium cyanide was 100 μgm. per ml. Thus there was, at this cyanide concentration, 50% of cyano-cobalamin with the fish meal suspension alone, and 64 and 61% respectively in the meals to which 500 mμgm. of cyano- or hydroxo-cobalamin had been added prior to autoclaving. It appears that cyanide, at least in the concentration used, did not cause complete conversion of the natural, or added, hydroxo-cobalamin to the cyano form in crude products. It is possible that there is a very high percentage of cyano-cobalamin in suspensions so treated, but that there is, with crude products, a pronounced conversion of cyano- to hydroxo-cobalamin during chromatography. The recovery of cobalamins as calculated from the sum of the separate assay values was good with the exception of the single high value with the one sample (123%). Occasional unusually high or low values occur in assays of this type.

Experiment 3

Aqueous 1:2 or 1:10 suspensions of salmon kidney and beef liver were disintegrated for one minute in a Waring Blendor. After removing small samples for chromatography of the raw products, the remainder was in each case autoclaved for five minutes at 120°C., cooled promptly, centrifuged briefly, and portions of the supernatant extracts were stored in stoppered tubes at 0°C. in the dark. Microbiological assays for total cobalamins were carried out in the usual manner, both directly and after chromatographic separation of the vitamins.

Qualitative results (Table V) indicated that in both raw and heated materials hydroxo-cobalamin, or a similar form chromatographically, occurs practically exclusively. The total cobalamin content of the kidney samples was high, particularly that from the sockeye salmon, and both had more than the sample of beef liver (Table VI). However, not all of this activity can be accounted for by cobalamins, for with beef liver, sockeye salmon kidney, and chum salmon kidney only 55, 71, and 91%, respectively, of the amount indicated by direct assay was recovered after chromatographic separation. It is possible that deoxypentosides accounted for some of the apparent vitamin B_{12} activity of these materials, for sockeye salmon kidney contains appreciable amounts of at least four of these (27). It has been shown that practically all of the vitamin B_{12} activity of certain crude animal protein products, including fish meal, is destroyed by treatment with alkali, and with these materials less than 8% of the total activity was accounted for by deoxypentosides (18).

TABLE V

QUALITATIVE DISTRIBUTION OF COBALAMINS ON CHROMATOGRAMS OF SAMPLES FROM EXPERIMENT 3

Product chromatographed	Approximate size of growth zone and average distance from point of application (cm.)	
	Zone corresponding to cyano-cobalamin	Zone corresponding to hydroxo-cobalamin
5 mμgm. of vitamin B_{12}	Large, 20	Small, 7.5
5 " " " B_{12a}	None	Large, 7.5
0.05 ml. of 1:4 raw chum salmon kidney suspension	No separate zones, continuous growth from origin to 23 cm.	
0.05 " " 1:4 autoclaved chum salmon kidney suspension	None	Long zone, 1-15 Av. 7
0.02 " " 1:4 " " " " "	None	Large, 8
0.02 " " 1:4 raw sockeye salmon kidney suspension	None	Long zone, 0-12 Av. 6
0.02 " " 1:10 autoclaved sockeye salmon kidney suspension	None	Large, 8
0.05 " " 1:2 autoclaved beef liver suspension	None	Long zone, 1-15 Av. 7
0.02 " " 1:2 " " " "	None	Large, 8
0.02 " " 1:4 " " " "	None	Large, 8

TABLE VI

VITAMIN B_{12} CONTENT OF SALMON KIDNEY AND BEEF LIVER AS DETERMINED BY DIRECT ASSAY AND ASSAY AFTER CHROMATOGRAPHIC SEPARATION

Product assayed and amount of suspension chromatographed***	Mμgm. of vitamin B_{12}-activity per gm.						
	Direct assay of extracts			Chromatographic separation, elution and assay			
	(1)*	(2)*	Av.	(1)	(2)	Av.	% Recovery**
Chum salmon kidney (0.02 ml. 1:4 suspension)	2230	1990	2110	2000	1844	1922	91
Sockeye salmon kidney (0.02 ml. 1:10 suspension)	3760	3567	3664	2580	2440	2510	69
" " " (raw) (0.02 ml. 1:10 suspension)				2760	2670	2715	72
Beef liver (0.05 ml. 1:2 suspension)	1620	1539	1580	900	972	936	59
" " (0.02 " 1:2 ")				890	760	825	50
" " (0.02 " 1:4 ")				874			55

7.6 mμgm. of vitamin B_{12} — 7.26 mμgm. recovered = 95%
5.0 " " " B_{12a} — 4.90 " " = 98%

Assay values under (1) obtained on the day of preparation and under (2) after five days at 0°C.
***Per cent of the value found by direct assay. The figure in this column for the raw salmon kidney is based on the direct assay of the heated extract. This indicates extraction was complete and the vitamin was not destroyed by heating.*
****All suspensions autoclaved for five minutes at 120°C. with the exception of the one sample of sockeye salmon kidney.*

DISCUSSION

In the natural animal protein materials examined vitamin B_{12} appears to occur very largely as hydroxo-cobalamin, or as a similar form chromatographically. It is possible that this slow-moving form is not hydroxo-cobalamin but is a "peptide conjugate" of the type said to occur in beef liver, condensed fish solubles, and other natural materials (10), or a mixture of sulphato-, chloro-, and other cobalamins. In view of this it would appear important that, unless the tissues extracted are assayed by a method which gives identical results with hydroxo- and cyano-cobalamins, only the former should be used as assay standard and the results expressed in terms of hydroxo-cobalamin. Alternatively, the extracts could be treated with cyanide or metabisulphite (17) and assayed with cyano-cobalamin as standard, or possibly, in media containing cyanide (6, 11). However, it would appear from the present results, and also from previous findings with crude fermentation liquors (24), that not all the cobalamin may be converted to the cyano form by cyanide treatment. Data regarding the quantitative nature of the conversion of hydroxo-cobalamin and other cobalamins to cyano-cobalamin in crude products seem to be lacking, and it is not clear whether very high concentrations of cyanide are required for nearly complete conversion, whether an equilibrium is established, or whether conversion proceeds slowly (10). The present work indicates that no appreciable destruction of the cobalamins occurs as a result of cyanide treatment. There is also the possibility that there is a greater conversion of cyano- to hydroxo-cobalamin during chromatography of these crude extracts than is normally experienced with crystalline vitamin B_{12} (24, 30) and thus distribution of the cobalamins on the chromatograms may yield a false picture of the relative amounts present. The fact that, in Experiment 2, there was about the same ratio of cyano- to hydroxo-cobalamin in potassium cyanide-treated extracts to which either one of these forms of the vitamin had been added prior to heating suggested that an equilibrium is established. This equilibrium might be shifted by higher concentrations of cyanide. However, in previous work the addition of 2.5 mgm. of potassium cyanide per ml. of certain crude fermentation liquors (24) (at pH 5.5) did not occasion complete conversion of hydroxo- to cyano-cobalamin.

In conclusion it is of interest to note that the assay of certain crude liver concentrates by a chemical method involving the quantitative measurement of the cyanide from cyano-cobalamin in the potassium cyanide-treated materials yielded much lower results than did microbiological assays for total cobalamins. In this work it was also reported that only 83% of added hydroxo-cobalamin was recovered from one of these preparations, while added cyano-cobalamin was always recovered quantitatively within the probable limits of accuracy of the method (2). One is tempted to wonder whether these discrepancies were due to differences in assay results between microbiological and chemical methods, or whether the hydroxo-cobalamin (or other cobalamin) in these crude materials was not quantitatively changed to cyano-cobalamin under the experimental conditions.

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GREENLAND COD (*GADUS OGAC*) IN MIRAMICHI BAY, NEW BRUNSWICK.—Until Vladykov (1945, Naturaliste Canadien, 73 (1 et 2): 28–31) reported finding it in fair numbers from Belle Isle Strait westward along the north shore of the Gulf of St. Lawrence, there were no other records of *Gadus ogac* Richardson in the Gulf. However, in late March, 1949, two specimens were taken off Portage Island just inside Miramichi Bay in eastern New Brunswick, about 200 miles still farther south than the places where this species was found by Vladykov.

To the local French fishermen these fish are known by the name of "Pilot" and to the English-speaking fishermen as "Rock Cod." They are reported to occur as far up Miramichi Bay as Oak Point; that is, almost to the head of the Bay. Reports as to their abundance vary, seemingly according to where the smelt fishermen operate during the winter, some claiming to catch one to five almost every winter, while others see them only every four or five years.

During the summer they are said to be taken occasionally in lobster pots, while a few fishermen claim to have found them so abundant on certain cod-jigging grounds that they were forced to shift their operations for lack of larger cod. Reports as to their size indicate that they range from 14 to 18 inches, rarely larger. Some fishermen claim they are no good for food (at least in winter) as the flesh is greyish in colour and becomes very soft, falling apart when cooked unless cooked in the round.

The measurements (in mm.) and counts of our two specimens, 352 mm. and 398 mm., respectively, in standard length, are as follows: head length: 113, 118; eye: 15, 19; snout: 39, 42; length of upper jaw: 51, 53; interorbital space: 31, 32; barbel length: 10 (mutilated), 21; pectoral length: 66, 68; caudal peduncle depth: 20, 20; rays in first dorsal: 14, 13; second dorsal: 15, 16; third dorsal: 13, mutilated; rays in first anal: 17, 19; second anal: 15, 18. The peritoneum is black in both specimens.

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One of our two specimens was sent to the Royal Ontario Museum of Zoology, Toronto, where Dr. W. B. Scott, Curator, Division of Ichthyology and Herpetology, verified it, and it is now in their collections under catalogue number 13,994.—R. A. McKenzie, *Atlantic Biological Station, St. Andrews, N. B., Canada.*

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Experimental Preservation of Flesh Foods with Antibiotics[a,b]

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The preservation of fish and meat with streptomycin, penicillin, subtilin, polymixin B, circulin, neomycin, bacitracin, gramicidin, metholyl gramicidin, tyrothricin, rimocidin, terramycin, chloromycin, aureomycin, and one unnamed antibiotic has been investigated. Aureomycin, terramycin, and chloromycetin, in the order named, proved the most effective inhibitors of growth of the natural mixed bacterial flora at temperatures between 0° C. and 21° C., while rimocidin inhibited yeast growth. Aureomycin caused marked inhibition of spoilage in 0.5 to 2.0 γ per g. concentration when incorporated in minced flesh, and was equally effective when applied by immersing steaks in solutions containing the antibiotic in 5 or 10 γ per ml. concentration. The remaining twelve antibiotics in 10 to 50 γ per g. concentration either exerted a less intense bacteriostatic action or were without effect.

One definition of the term antibiotic is, "a chemical compound derived from or produced by living organisms, which is capable, in small concentrations, of inhibiting the life processes of microorganisms" *(3)*. The early application of antibiotics was in medicine, but

[a] Presented at the Twelfth Annual Meeting of the IFT, Grand Rapids, Mich., June 9, 1952.

[b] (Editor's Note: The physiological effects of various antibiotics, if used in foods, has not been clearly established. Practical use of these agents in foods is not permitted at the present time.)

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during the past two or three years their use has been extended to include animal feeding, for they frequently occasion a pronounced growth stimulus when included in rations of certain young domestic mammals and birds. The possibility of employing antibiotics to preserve human foods from undesirable bacterial attack has been recognized for several years, but there has as yet been no apparent practical application, and research on the subject has been rather limited.

Experiments with penicillic acid *(9)*, and later with streptomycin and penicillin *(11)*, indicated that they had a negligible or feeble bacteriostatic action in fish flesh stored at 0°C. Ground meat, inoculated with various *Clostridia* and incubated at 37°C. anaerobically was preserved fairly effectively for 5 or 10 day periods *(6)* with 20 γ per g. of a mixture of subtilin and streptomycin. In the same work it was reported that subtilin, penicillin, or streptomycin alone were less effective than the above mixture, and that tyrocidin and chloromycetin had little preservative action. Other investigators *(1)* reported that growth of strict anaerobes in comminuted beef was inhibited by only high concentrations of subtilin (100 or 1000 γ per g.), and that the effect of this antibiotic was probably transient. It has been shown that milk can be temporarily preserved against bacterial spoilage by penicillin *(5)* and that certain plant extracts, which possibly should not be termed antibiotics, act as bacteriostats in curing brines *(7)*. The possibility that processing temperatures and times in the canning of vegetables could be reduced if subtilin were used as a bacteriostat has been recognized *(2)*. However, further work has indicated that, though antibiotics may yet be of some value for this purpose, subtilin is not likely to prove reliable *(4)*.

It would seem that the use of antibiotics in non-canned foods offers more promise than does their addition to foods with the object of preventing bacterial spoilage of the canned product: in the former a transient bacteriostatic action may often suffice, while in the latter permanent inhibition of bacterial growth is usually mandatory. The present work is concerned with the first-named problem, and a note concerning the early results has been published *(12)*.

EXPERIMENTAL METHODS

Flesh of strictly fresh fish was obtained under conditions designed to minimize bacterial contamination. The beef used was obtained from freshly-slaughtered animals and was handled under similar conditions. Two methods of testing the various antibiotics were employed. In the first the flesh was passed through a domestic mincer equipped with a plate with 4 mm. diameter holes, and 95-g. portions were placed in 8-ounce sterilized screw capped glass jars. The antibiotic solutions were prepared immediately prior to use either as aqueous solutions, or, in the case of tyrothricin, gramicidin, and metholyl gramicidin, as solutions in 50% ethanol. Then 5-ml. portions of solutions of the required concentration were incorporated into the 95-g. samples of flesh and the containers stored at the desired temperature. The second method of application merely consisted

TABLE 1

Effect of antibiotics on growth of bacteria in halibut flesh at 0° C. (initial pH 6.2)

Antibiotic	Concentration	Bacteria × 10^6 per g. after		
		6 days	10 days	18 days
	γ per g.			
None	0	38.0	1600.0	.....[c]
None	0	44.0	950.0	.....[c]
Aureomycin hydrochloride	50	0.01	0.08	1300[d]
Aureomycin hydrochloride	25	0.01	0.35	1500[d]
Chloromycetin	50	0.10	79.0	3700[c]
Chloromycetin	25	0.24	230.0	.....[c]
Subtilin	50	30.0	720.0	.....[e]
Subtilin	25	20.0	680.0	.....[e]
Sodium nitrite	200	0.10	44.0	.....[e]

[c] Putrid. [d] All cells were yeasts.

TABLE 2

Effect of antibiotics on growth of bacteria in red spring salmon flesh at 3° C. (initial pH 6.2)

Antibiotic	Concentration	Bacteria × 10^6 per g. after	
		7 days	12 days[e]
	γ per g.		
None	0	32.0	3300
Aureomycin hydrochloride	50	0.0	0.27
Aureomycin hydrochloride	25	0.023	0.75
Aureomycin hydrochloride	10	0.0	3.2[f]
Chloromycetin	50	0.09	530
Chloromycetin	25	1.3	1400
Chloromycetin	10	3.7	4000
Subtilin	50	12.0	3900
Subtilin	25	31.0	3200
Sodium nitrite	200	0.08	20

[e] All samples except that treated with sodium nitrite showed severe pigment bleaching and rancidity.

[f] All cells were yeasts.

in immersing steaks of the required size for 1 minute in an aqueous solution of the antibiotic at about 10° C., draining for a short time to remove surplus liquid, wrapping in moisture-proof cellophane, and storing.

Comparative rates of microbiological spoilage of stored samples were determined as follows. A 25-g. portion was blended with 75 ml. of distilled water for about 1 minute, and two 0.1-ml. amounts were used to make duplicate preparations for a direct microbiological count *(10)* using North's staining procedure *(8)*. This counting method is rapid, yields results similar to those obtained by viable methods, gives relatively permanent

TABLE 3

Effect of antibiotics on growth of bacteria in brill flesh at 3° C. (initial pH 6.2)

Antibiotic	Concentration	Bacteria × 10^6 per g. after	
		7 days	11 days
	γ per g.		
None	0	9.8	1500
Aureomycin hydrochloride	25	0.023	0.6
Aureomycin hydrochloride	10	0.023	<0.1
Terramycin hydrochloride	25	<0.01	<0.1
Terramycin hydrochloride	10	0.023	0.8
Chloromycetin	50	0.04	300
Chloromycetin	25	<0.01	390
Chloromycetin	10	0.22	2900
Penicillin	50	2.9	1900
Penicillin	25	1.6	680
Streptomycin	50	1.2	64
Streptomycin	25	1.1	100
Streptomycin	10	2.4	510
Sodium nitrite	200	<0.01	200

TABLE 4

Effect of antibiotics on growth of bacteria in coho salmon flesh at 3° C. (initial pH 6.2)

Antibiotic	Concentration	Bacteria × 10^6 per g. after		
		7 days	11 days	15 days
	γ per g.			
None	0	4.0	4500	.....
Aureomycin hydrochloride	10	<0.01	0.066	6.9[a]
Aureomycin hydrochloride	5	<0.01	0.053	32
Aureomycin hydrochloride	2	<0.01	0.053	350
Terramycin hydrochloride	10	<0.01	4.2	550
Terramycin hydrochloride	5	0.026	190	3500
Terramycin hydrochloride	2	0.21	730	4700
Neomysin sulfate	50	0.90	2400	....
Neomysin sulfate	25	0.82	2300	.....
Circulin sulfate	50	0.08	480	4900
Circulin sulfate	25	0.08	650	4300
Polymixin B	50	0.026	670	4200
Polymixin B	25	0.200	960	4500
Sodium nitrite	200	0.013	14	2300

[a] Some yeasts.

TABLE 5

Effect of antibiotics on growth of bacteria in lingcod muscle at 0° C. and 3° C. (initial pH 6.6)

Antibiotic	Concentration	Bacteria × 10^6 per g. after days at [1]					
		3° C.			0° C.		
		6	10	13	6	10	13
	p.p.m.						
None	0	1300			12	1200	3000
Aureomycin	2	1.3	31Y 1.2B	64Y 4.3B	0.11	0.026Y 0.43B	1.6Y 0.5B
Aureomycin plus rimocidin	2 10	0.92	1.0B	0.5Y 8.0B	0.026	0.26	0.6B
Aureomycin plus rimocidin	2 2	0.38	4.0Y 0.4B	48.0Y 5.6B	0.026	0.30	0.2Y 0.3B
Rimocidin	10	..... [h]	.....	.....	16	870	2500
Rimocidin	50	..... [h]	.....	.....	14	900	2600
Tyrothricin	50	1300	.....	.....	3.2	90	3000
Tyrothricin	10	1200	.....	.....	14	600	2700
Gramicidin	50	51	.....	.....	0.64	5	16Y 15B
Gramicidin	10	640	.....	.....	15	1100	2900
Metholyl gramicidin	50	16	.....	.....	0.29	3.3	100
Metholyl gramicidin	10	1400	.....	.....	8.1	800	2600
Polymixin B	50	640	.....	.....	4.7	26	3400
Polymixin B	10	1100	.....	.....	7.6	18	2800
631-51R788	50	1300	.....	.....	10.2	270	600
631-51R788	10	1400	.....	.....	15	1100	3200
Penicillin plus Streptomycin [i]	50	600	.....	.....	6.4	430	2300
Penicillin plus Streptomycin [i]	10	1060	.....	.....	10.2	1200	2900

[h] Putrid. [i] Equal quantities of each. [j] Y indicates yeast cells; B, bacteria.

preparations and permits an approximate differentiation of bacteria from yeast cells. However, it is rather inaccurate when bacterial populations of less than 1×10^5 per g. are involved *(10)*.

RESULTS

In Tables 1 to 6 the results obtained in experiments with minced flesh of different fish are recorded. In the first four experiments sodium nitrite was included because it has found extensive use in Canada in fresh fish, where it is permitted in concentration not exceeding 200 γ per g. (The Food and Drugs Act, page 76, Ottawa, 1949). It will be seen from the tables that aureomycin, terramycin, and chloromycetin were the only really effective antibiotics, their effectiveness being in the order given. In some instances certain of the

TABLE 6

Effect of antibiotics in 10 γ per g. concentration on growth of bacteria in halibut muscle at 18-21° C. (initial pH 6.3)

Antibiotic [k]	Bacteria $\times 10^6$ per g. after	
	1 day	2 days
None	10	4900 [l]
Aureomycin	<0.01	8 [m]
Aureomycin plus rimocidin	<0.026	4.9
Terramycin	0.13	12
Chloromycetin	0.15	360

[k] At this temperature neomycin, penicillin, streptomycin, polymixin B, bacitracin, gramicidin, tyrothicin, metholyl gramicidin, circulin, subtilin, equal amounts of penicillin and streptomycin, and rimocidin had only very feeble bacteriostatic action. Thus after 1 day the counts were between 1.1 and 2.7×10^6 per g., and all samples were putrid by the second day.

[l] Putrid. [m] Yeast cells.

other antibiotics did exert a definite and quite pronounced bacteriostatic effect (gramicidin and metholyl gramicidin). This effect was never as marked as that obtained with much lower concentrations of aureomycin, and was not as consistent. Rimocidin was ineffective alone, but when used with aureomycin it retarded the yeast growth which usually occurred with samples stored for some days with aureomycin as bacteriostat. Sodium nitrite was very effective in the comparatively high concentration used.

The single experiment with cooked crab meat (Table 7) is of interest in that, with this rather alkaline material, aureomycin and terramycin gave about the same degree of protection against bacterial spoilage, while in

TABLE 7

Effect of antibiotics on growth of bacteria in cooked crab meat at 3° C. (initial pH 7.9)

Antibiotic	Concentration	Bacteria × 10^6 per g. after	
		4 days	8 days
	γ per g.		
None	0	0.94	2700 [n]
None	0	1.2	2200 [n]
Aureomycin	20	<0.01	7.4 [p]
Aureomycin	10	<0.01	110 [p]
Aureomycin	5	0.053	320 [o]
Aureomycin	1	0.14	1300 [n]
Terramycin	20	<0.01	50 [p]
Terramycin	10	<0.01	280 [o]
Terramycin	5	<0.01	440 [o]
Terramycin	1	<0.01	630

[n] Putrid. [o] Stale odor. [p] Pleasant smell and taste.

all other experiments aureomycin proved more effective in a given concentration than did terramycin. Immersion of lingcod steaks in aureomycin solution (10 and 20 γ per ml.) caused a marked retardation of bacterial spoilage (Table 8). The bacteriostatic effect was so

TABLE 8

Effect of immersion in aureomycin solutions on growth of bacteria in lingcod steaks (initial pH 6.6; thickness about 2 cm.)

Solution used	Bacteria × 10^6 per g. at			
	3° C. after		0° C. after	
	6 days	9 days	13 days	23 days
Water	240	Putrid	330	Putrid
10 γ per ml. of aureomycin	<0.01	0.11	0.026	36
20 γ per ml. of aureomycin	<0.01	0.053	<0.01	12

marked that it would appear that dipping fish steaks in solutions containing even lower concentrations might prove satisfactory.

With minced beef only the three antibiotics which seemed of greatest interest in view of the foregoing experiments were investigated. The results (Table 9 and 10) indicated that as with fish, aureomycin is a somewhat more effective preservative for meat than is terramycin, but the differences were not as marked as those usually occurring with fish. In one series of experiments (Table 10) yeasts, and no noticeable bacteria, developed in the antibiotic-treated samples. Yeasts

TABLE 9

Effect of antibiotics on growth of bacteria in minced shoulder beef at different temperatures

Antibiotic	Concentration	Bacteria × 10^6 per g. at					
		0° C. after		4.5° C. after		18-21° C. after	
		8 days	23 days	4 days	8 days	1 day	2 days
	γ						
None	0	12	20,000 [a]	200	2,100	130	2,700
Aureomycin	1	0.1	1,500	0.66	280	0.01	300
Aureomycin	0.5	0.26	3,200	15	300	4.0	850
Aureomycin plus rimocidin	1.0 10.0	1.2	440	5.5	24.0	2.9	8.3
Aureomycin plus rimocidin	1.0 5.0	0.58	490	0.69	79	0.52	200
Terramycin	5.0	0.19	850	8.0	110	0.90	140
Terramycin	2.0	0.95	6,000	25	50	3.6	300
Terramycin plus rimocidin	2.0 10.0	14	20,000 [a]	37	860	8.0	3,100
Terramycin plus rimocidin	2.0 5.0	17	20,000 [a]	11	690	4.3	290

[a] These preparations were almost uncountable, and consequently the figures given are only rough approximations.

TABLE 10

Effect of antibiotics on growth of bacteria in minced beef shank meat at different temperatures

Antibiotic	Concentration	Bacteria × 10^6 per g. at 4.5° C. after 7 days	Bacteria × 10^6 per g. at 4.5° C. after 16 days	Bacteria × 10^6 per g. at 0° C. after 23 days
	γ per g.			
None	0	0.66	50,000 [r]	2,900
Aureomycin	10	<0.01	26Y [s]	5.8Y
Aureomycin	5	<0.01	58Y	4.6Y
Aureomycin	2	<0.01	37Y	6.6Y
Aureomycin	1	<0.01	58Y 90B	4.0Y
Terramycin	10	<0.01	95Y	9.0Y
Terramycin	5	<0.01	140Y 20B	3.7Y
Terramycin	2	.....	.....	720 B and Y

[r] Almost uncountable. [s] Y, indicates yeasts; B, bacteria.

failed to develop in significant numbers in the other experiment in which rimocidin had been included in order to determine its effectiveness in inhibiting their growth. However, in the experiment in which beef steaks were dipped in aureomycin solutions (Table 11) rimocidin caused a very pronounced retarding effect on the yeast development which occurred with aureomycin alone.

TABLE 11

Effect of immersion in aureomycin and rimocidin solutions on growth of bacteria in round steaks stored at 4.5° C. for 12 days. (Thickness about 1.5 cm., weight roughly 300 g.)

Solution	Bacteria × 10^6 per g.
Water	2000
Aureomycin, 5 γ per ml.	5.8Y [t]
Aureomycin, 10 γ per ml.	6.5Y
Aureomycin, 20 γ per ml.	2.0Y
Aureomycin, 5 γ per ml. plus rimocidin, 10 γ per ml.	0.053Y
Aureomycin, 5 γ per ml. plus rimocidin, 20 γ per ml.	<0.01
Aureomycin, 10 γ per ml. plus rimocidin, 10 γ per ml.	<0.01
Aureomycin, 10 γ per ml. plus rimocidin, 20 γ per ml.	0.053Y

[t] Y, Yeast cells.

Acknowledgments

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The Jacket Principle...

in Canadian Cold Storage

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The Jacket Principle...

in Canadian Cold Storage

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With frozen foods on the rise there is a need for better methods of cold storage. Little used at present, the jacket principle may be the "better mouse trap" of the low-temperature warehouse.

The need for improved cold storage facilities is becoming increasingly acute because of the ever-growing demand for perishable foods preserved through freezing. The increased demand for frozen foods stems from improved quality which in turn stems from a better understanding of the problems connected with freezing as a means of preservation. Although there is considerable knowledge available on freezing preservation of foods there is much still to be learned, and there is still much to be done in the way of applying what knowledge we do have. Research has revealed the adverse effects of cold storage on some artirles of food and has gone a long way towards showing how storage conditions can be improved. But there seems to be too much hesitancy or too much lag on the part of industry to apply the knowledge relating to effects of long storage under low temperature conditions.

It is not necessary to go into details concerning the specific reactions that caused degradation in quality in stored frozen foods. The effects of decomposition, dehydration and oxidation are fully described in the literature. The purpose of this paper is to indicate some of the ideas that have been applied in Canada to minimize some of these actions by structural means.

Fish Were a Problem

Although the observations which follow have general application they deal principally with cold rooms used for the storage of frozen fish because the difficulties experienced in the holding of frozen fish for extended periods in the "orthodox" type of cold room gave rise to the modifications which will be described.

It might be explained that the term "orthodox" as applied to cold rooms refers to rooms refrigerated by cooling coils on the ceilings. Those who have visited cold storage plants in Canada and the United States of America will recall that practically all rooms in which temperatures below the freezing point of water are held on this continent are cooled this way, so the term will be readily understood.

Orthodox cold rooms have always imposed a serious dehydration problem, and have been the cause of great degradation in quality of frozen fish stored in them, through drying and through increased oxidation resulting from the failure of protective coatings such as glazes.

Engineers tells us that the drying effect in a cold room is dependent upon such factors as the area exposed to wide temperature differences; the area of the cooling surface exposed in the room; the thickness of insulation; and the actual constructional details all of which fall within the scope of the designer. It is surprising, therefore, that until comparatively recently little effort had been made by designers to reduce drying through structural means. The main effort in the past has been devoted to the development of protective coatings such as glazes, latex bags and moisture vapour-proof wrappers for frozen commodities to be stored.

Huntsman Was First

In Canada records indicate that the first worker to investigate the possibility of reducing drying by means of structural modifications was Dr. A. G. Huntsman, (1) not an engineer but a man with training in biology and medicine. Dr. Huntsman, while Director of the Atlantic Fisheries Experimental Station at Halifax, carried out some experiments on the freezing and storage of fish fillets and thus came to recognize the seriousness of the drying that took place in ordinary cold storage rooms. Consequently he devised what he called the "jacketed cold storage room" for experimental purposes at the Halifax Station in 1927. This work was done under the auspices of the Fisheries Research Board of Canada which at that time was called the Biological Board of Canada. Results obtained with this room and with another built in St. Andrews, New Brunswick. in 1929 indicated that drying could be greatly reduced by jacketing, but no practical use was made of these results.

In 1931 and '32, studies were conducted on the West Coast, again by the Fisheries Research Board, to relate the drying effect in cold rooms to some of the controllable factors involved. By jacketing, the effect was reduced to approximately one-seventh of that in a "control" room. But these results, though

of great practical significance, seemed to make little impression upon refrigeration engineers for the commercial cold stores that were built in Canada in the late '30's and up to the middle '40's followed the old pattern with shelf coils in freezers and ceiling coils in cold rooms. By the middle '40's however the occasional fish freezer had fans to reduce the freezing time through mechanical agitation of the air.

This increased air agitation caused a slight increase in the loss in weight of dressed fish over that ordinarily sustained, but this was simply restored through the glazing process, and care was always taken to keep the drying below the level of noticeability. Through experience operators soon learned of the drying characteristics of their freezers and estimated just when the fans must be operated.

Other Attempts to Cut Drying Loss

Cold rooms too have their particular peculiarities which are soon discovered by the operators who use various means to deal with them. For example, attempts to reduce losses through drying in some cases were made by means of spraying the walls and floor and thus coating them with ice; by spraying the fish after they were piled in the rooms; by the use of "special" glazes; and by the use of floor and wall "grids" such as are shown diagramatically in Figure 1. These grids did help somewhat but they were by no means completely satisfactory, for after prolonged storage the fish did dry out in regions of the fish piles next the floor and wall.

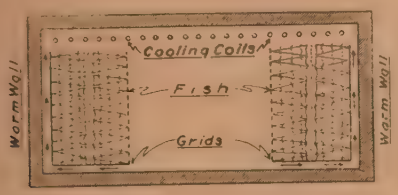

Figure 1.

Variations in the drying effect between rooms and even within rooms baffled some operators to such a degree that they eventually sought technical help. The drying in most cases was not difficult to explain but to overcome the causative defects was quite another matter. With the co-operation of a few plant operators, however, many ideas were followed up that resulted in rather useful designs for the reduction of drying in the orthodox type of cold room. In the hope that some of the helpful modifications that came out of the studies may be of interest to the reader several types will be described.

Figure 2 shows the simplest of these applied to a cold room that has one or more walls subject to external conditions and which are, therefore, called "warm" walls. Drying in frozen commodities piled near such walls is particularly bothersome and it was found that the single wall grid as shown in Figure 1 was not very effective. A double jacket as shown in Figure 2 was found to be much more effective. It will be noticed that the double jacket is so arranged that the cold air from the ceiling coils can descend within the inner jacket, and since it will not pick up heat appreciably on its way down, its temperature will not change in this descent. At the bottom of the duct the circulating air will commence to pick up heat and will be drawn into the outer duct to

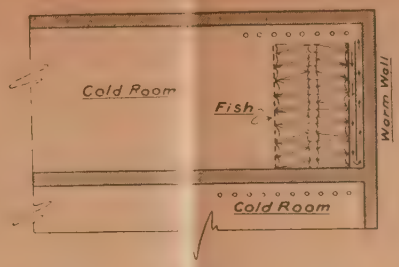

Figure 2.

take the place of the warmed air there which rises due to reduced density through the heating effect of the warm wall. In this arrangement it is important that the outer jacket be carried up to the level of the cooling coils and that the inner jacket be somewhat lower than this. Furthermore, the resistance to the cold air descending from the coils into the inner duct must be the least possible.

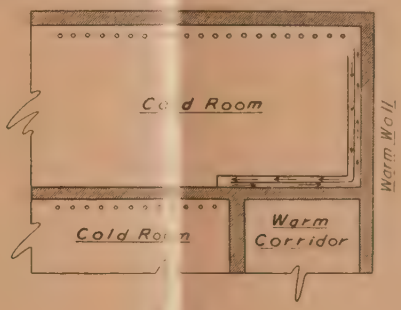

Figure 3.

A somewhat more complicated arrangement of jackets is required where the whole floor or part of it, as well as one or more walls are warm, as shown in Figure 3. Here the double jacket must be extended over all that portion of the floor that is warm, and must connect with the double jackets upon that warm wall which will provide the shortest path for the air circulating through both jackets.

Where the floor and all the walls are warm it is necessary to have an arrangement somewhat as shown in Figure 4. The circulation of the air is as indicated, and the same precautions regarding the level to which the inner and outer jackets must be carried upward, as previously mentioned, must be taken. An indication of how the fish may be piled to form a funnel into the inner duct is shown, but precautions must be taken to prevent small fish from ob-

Figure 4.

structing the opening into the inner duct or from falling into it.

The superiority of the double jacket arrangement, over the single floor and wall grids shown in Figure 1, even though only necessary on warm walls and floors, pose the question: "if jackets are so important in rooms in which frozen fish are to be stored, why are they not installed when the plant is erected?" Such questions and others concerned with the saving of space and increased efficiency obtainable through mechanical rather than natural air circulation, have paved the way for the introduction in Canada of the jacket principle advocated by Dr. Huntsman.

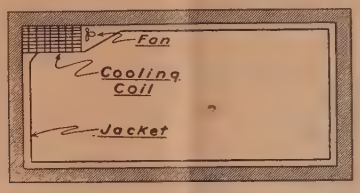

Figure 5.

It is not intended to create the impression that the jacket system is generally accepted by refrigeration engineers in Canada. Indeed at the moment there are only two or three plants in Canada in which the principle has been applied throughout. These plants are getting such favourable results, however, and are exciting such interest that there are good grounds for the belief that the principle will be applied in most future plants in which frozen fish in bulk will be stored.

For the sake of completeness Figure 5 is added to show diagramatically the jacket principle as applied to a cold room. The principle, and its advantages have been described fully elsewhere (2) and its application is not restricted by patents.

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TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA

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SECTION FIVE

"Even-year" and "Odd-year" Pink Salmon Populations

FERRIS NEAVE

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SINCE pink salmon (*Oncorhynchus gorbuscha*), to the best of our current knowledge, invariably mature and die at the end of the second year of life, it has long been recognized that the adult runs appearing in any two consecutive years represent entirely separate populations of the species. Since these stocks for the most part occupy the same regions and spawn in the same watercourses, special opportunities are provided for comparing the status and fortunes of two populations possessing similar constitutional and geographic opportunities but entirely prevented from interbreeding.

Particular interest attaches to well-known cases in which the disparity in abundance between the stocks is so great that years of immensely productive fishing alternate regularly with years which yield insignificant returns from the same waters.

This situation has sometimes led to the belief that the existence of a very large stock in one series tends to suppress the population of the other series—a view which has been more fully developed in relation to a somewhat similar phenomenon of "dominance" exhibited by the sockeye (*O. nerka*) populations of the Fraser River watershed (Ricker, 1950).

Whether or not the causes of population disparity in pink salmon can be immediately elucidated, a decision about the independence or otherwise of each population with respect to the other would in itself be helpful to the conservationist. If it were shown that the existence of two large populations in the same waters is biologically incongruous, fisheries management would have to work within the limitations of this framework. If on the other hand there is no fundamental incompatibility, efforts can be directed towards discovering and removing the causes of weak stocks.

In evaluating the evidence bearing on this problem it is pertinent to survey the available information concerning the geographic status of pink salmon belonging to the two great branches of the species, that is, fish maturing in "even" years and fish maturing in "odd" years. For

convenience, these two kinds of pink salmon are designated herein as "E fish" and "O fish".

Relative Abundance of E- and O- Pink Salmon

1. In British Columbia

Past records of the abundance of adult pink salmon (that is, "catches" and "escapements") for the numerous administrative areas of the British Columbia coast cannot be regarded as accurate in an absolute sense. They are undoubtedly adequate, however, to show the direction of major changes in abundance from year to year or to reveal marked discrepancies between a series of even years and a series of odd years.

Table I presents certain such estimates of catches for areas of the northern and central coastal regions of British Columbia. These areas

TABLE I

Relative Abundance of E and O Pink Salmon, in Northern B.C., as Indicated by Reported Annual Catches

Area	Period	*Average catch (wt.)* E	O	*Ratio* E:O
North Queen Charlotte Is.	1930-1949	45,994	224	205:1
South Queen Charlotte Is.	1934-1949	14,901	1,381	11:1
Nass River	1930-1949	39,183	20,323	1.9:1
Skeena	1930-1949	51,313	47,933	1.1:1
Grenville-Principe	1930-1949	31,715	13,629	2.3:1
Butedale	1930-1949	59,192	39,430	1.5:1
Bella Bella	1930-1949	17,780	35,780	1:2
Bella Coola	1930-1949	22,538	37,985	1:1.7
Rivers, Smith Inlets	1930-1949	5,008	8,601	1:1.7

TABLE II

Relative Abundance of E and O Pink Salmon in Southern B.C., as Indicated by Reported Annual Escapements*

Area	*Period*	*Average escapement* (1000^s) E	O	*Ratio* E:O
Quathiaski	1934-1949	213.8	109.5	2:1
Comox	1934-1949	110.4	165.0	1:1.5
Toba Inlet	1934-1949	11.8	117.1	1:9.9
Jervis Inlet	1934-1949	58.1	167.4	1:2.9
Nanaimo	1934-1949	4.0	5.3	1:1.3
Clayoquot	1934-1950	2.8	1.9	1.5:1
Quatsino	1935-1946	167.0	3.8	44:1
Sooke Trap catch*	1938-1949	.474	126.3	1:266

*The Sooke Trap catch is included as being the best available indicator of the ratio between E and O fish travelling to Puget Sound and the Fraser River.

are defined in Fig. 1. For the southern portions of the coastline, catch figures cannot readily be used as an indication of the condition of the stocks "belonging" to individual areas, since many of the fish caught

are transients migrating to other destinations. In particular, the large biennial runs to the Fraser River and Puget Sound pass through and influence the catches of many other fishing areas. For these areas, therefore, comparisons have been made (in Table II) on the basis of reported escapements to the spawning streams. Because of the difficulties involved in making estimates of spawning populations in a vast number of streams of different size and character, these figures are

FIGURE 1.—Coastal regions of British Columbia, showing areas referred to in text. Stippling (Queen Charlottes) represents area in which streams show no extreme disparity (see text).

presented only for the purpose of demonstrating the gross features discussed below. Actually, estimates are commonly made as categories, for example "between 2,000 and 5,000"; "between 50,000 and 100,000." The figures used have been arrived at by taking the midpoints of the various categories.

Reviewing the 17 areas represented in Tables I and II, it is at once evident that two of them show an extreme degree of disparity between

E and O fish, the north Queen Charlottes having an overwhelming preponderance of E pinks and the Fraser–Puget Sound runs an equally impressive dominance in the O stocks. A third area (Quatsino) shows a pronounced but less extreme disparity favouring the E population. In all other areas the difference, for the periods quoted, is of a much lower order. Although the maintenance for several generations of a two- or three-fold difference in the magnitude of E and O catches sometimes leads in common parlance to the recognition of alternate "off" years and "on" years, the leading position not infrequently changes from one stock to the other (see Figs. 3 and 4). For nearly all of the areas listed in Tables I and II a shorter period of years could be selected which would reverse the preponderance suggested by the ratios given in these tables.

Since each of the areas referred to possesses numerous salmon streams, it would theoretically be quite possible for this general condition of near-equality of the stocks to represent merely the combined output of numerous spawning grounds which, taken individually, might show great disparity between E and O stocks. If E and O fish tended to spawn in different streams, an underlying similarity between the phenomenon observed in the Fraser and Queen Charlotte areas and the situation existing elsewhere could be established.

Observations made by personnel of the Fisheries Research Board and the much more comprehensive surveys of the Department of Fisheries show, however, that there is no such segregation of the breeding places of the two stocks. An examination of Departmental records shows clearly that in general the individual streams reflect closely the ratios shown by the commercial catches in the sea. The writer has seen reports relating to more than 200 pink salmon streams in the "sub-equality" areas of British Columbia, each stream being covered for a period of from 7 to 17 years. In no single instance has he found evidence of a degree of disparity between stocks which is at variance with the general picture obtained from the consideration of large areas. In most cases an overlap is indicated in the abundance of fish belonging to E and O populations.

A few specific examples may be cited from many streams showing a very high order of abundance in both odd and even years. The writer is personally familiar with the streams mentioned.

The Neekas River, in the Milbanke Sound area, has an accessible length of about one mile and an average width of about 20 yards. It supports large runs of both pink and chum (*O. keta*) salmon and the spawning grounds appear to be fully occupied by the presence at any given time of 40,000 salmon. Between 1935 and 1945 estimates of pink

salmon alone were of the order of 75,000 or higher in four even years and five odd years.

Evelyn Creek, on Hawkesbury Island, is a very small stream, about one and a half miles long. The flow on September 1, 1945, at the time when the adult fish were beginning to enter, was estimated to be only 6 c.f.s. (this was undoubtedly an unusually low level). Escapements of between 50,000 and 100,000 pink salmon were assigned to this stream in 1942, 1943 and 1945. The assumption of errors up to several hundred per cent would not alter the conclusion that full utilization of available spawning ground was being made by both E and O fish.

The Koeye River, flowing into Fitzhugh Sound, is well known to fishermen and Departmental officers as a large and constant contributor to the catches of the Queen Charlotte Sound area. It is a somewhat larger stream than those previously mentioned but the favourable spawning areas probably do not total more than three miles in length. Both even- and odd-year escapements are commonly estimated as "over 100,000." For recent years of both series this is believed to be a very conservative statement.

While they do not change the general impressions formed from an examination of catch figures, stream reports do, however, enable us to define more precisely the boundaries of the Queen Charlotte Island region which is characterized by extreme disparity. From Table I it would appear that only the northern portion of Graham Island displays this condition in an acute form, the rest of the island group showing only a moderate degree of E dominance. Departmental records make it clear that in fact most of the pink salmon streams of both Graham and Moresby Islands have virtually no runs in the odd years. A few rivers, however, located in a belt which extends on both sides of Skidegate Channel, have good or fair runs in both even and odd years and in fact show almost precisely the same state of affairs as the streams of the opposite (mainland) coast of Hecate Strait (see Fig. 1). Streams which can be named as belonging in this category are: Tlell River, flowing to the east coast of Graham Island; Riley Creek, flowing to the west coast of Graham Island; Copper River, flowing to the east coast of Moresby Island; Deena River, flowing to the north coast of Moresby Island (Skidegate Channel).

As regards the freshwater situation, therefore, most of Graham and Moresby Islands can be designated as a region of extreme E and O disparity, with a small central area which transects this region and which shows a condition characteristic of most other parts of the British Columbia coast.

In the southern mainland region the writer knows of no streams

which provide exceptions to the thoroughgoing dominance exhibited by the O fish, although the abundance of these varies considerably in different generations. E fish, however, are not entirely absent, having been reported in small numbers in many of the same watercourses. The disparity is not confined to the Fraser River watershed, being characteristic of streams in the adjacent districts of Puget Sound and Howe Sound. It does not extend to the southern end of Vancouver Island nor to the streams of Jervis Inlet.

The existing conditions with respect to the relative abundance of E and O fish in British Columbia as a whole can be summarized as follows:

1. Throughout the greater part of the range of the species within or near the province, a long-term condition of near-equality exists, with either stock capable of showing greater abundance in certain years or periods.

2. Throughout the periods for which records are available, local conditions of extreme disparity have prevailed in the Queen Charlotte Islands and in the southern mainland area. A less extreme disparity has existed in the Quatsino area of northwest Vancouver Island.

3. The ratios between E and O fish are characteristic of *regions* and are not the exclusive property of individual streams. Even the apparently mixed situation on the Queen Charlotte Islands appears to partake of this regional nature.

2. In Other Regions

The total geographic range of the pink salmon, excluding sparse or infrequent occurrences in Oregon and California, extends from the state of Washington northward along the American coast to northern Alaska and the Mackenzie River. On the Asiatic side of the Pacific it ranges southward as far as northern Korea and northern Honshu. Such data as the writer has seen relating to the comparative abundance of E and O fish throughout the greater part of this vast realm are mainly in the form of catch records for very large districts within which there is an obvious possibility of diverse local conditions. Nevertheless, even general information from the much greater territories occupied by pink salmon elsewhere is helpful in assessing the problem of disparity as witnessed in British Columbia.

The following remarks concerning Alaska are based on the annual catch figures supplied by the U.S. Fish and Wildlife Service and the canned packs reported in the *Pacific Fisherman Yearbook*. During the last fifteen or twenty years each of the seven recognized statistical districts of southeast Alaska shows much overlapping in the quantities reported for even and odd years. The total range of variation tends to

be of a similar order for both stocks and their relative abundance can be said to be in general accord with the condition which prevails along the greater part of the British Columbia coast. The same may be said of the five districts of central Alaska (comprising the region from Cape Spencer to the Alaska Peninsula) for which pink salmon packs are reported (in Cook Inlet the E fish are considerably more numerous on balance but there is no disparity of the extreme and persistent type to which reference has been made). In western Alaska (Bristol Bay, Yukon, etc.) certain series of figures give the impression of a thoroughgoing disparity favouring the E fish. The record is not consistent in this respect, however, and, since pink salmon catches are always relatively small in this region, it seems unsafe to draw definite conclusions regarding the ratio of the populations.

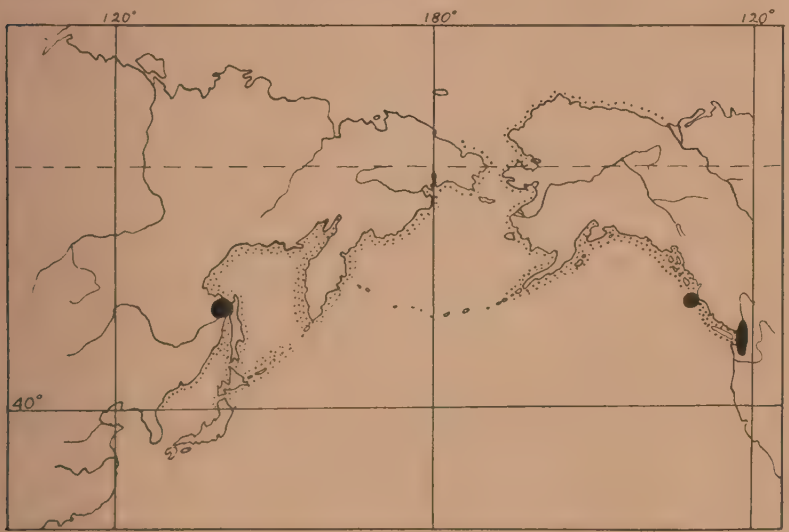

FIGURE 2.—North Pacific region, showing general distribution of pink salmon and (in black) areas of extreme disparity.

On the Asiatic side Pravdin (1940) quotes catch figures for the years 1926 to 1934 inclusive for each of 10 regions of the U.S.S.R. coast. From south to north these are: Primor; Nikolaevsk; Sakhalin; Okhotsk; Gijiginsk; Ichinsk; West Kamchatka; East Kamchatka; Karagin; Olyutoro-Navarin. The figures given show some degree of overlapping between E and O fish for six of these districts (in the two northernmost sections the leading position appears to have swung from the E to the O stock within the period). In the four regions for which no overlap is

indicated, the ratio is nevertheless quite low (7.5:1 or less) in two cases. Of the two remaining districts one, Gijiginsk, appears to be a relatively unimportant producer of pink salmon. The ratio obtained from Pravdin's figures is 31:1 in favour of the E stock—or roughly the condition prevailing in the Quatsino Sound area of British Columbia. The other exception is Nikolaevsk, which includes the very important fisheries at the mouth of the great Amur River. Here, the indicated disparity is even more extreme than that of the Fraser River area—but in favour of the E stocks. A further parallel can be seen in that the condition apparently does not extend to Sakhalin Island, the geographic relationship of which to the Amur is rather like that of Vancouver Island to the Fraser. Of especial interest, however, is the information supplied by Berg (1928) that the condition in the Amur district is of recent origin. Berg's figures for pink salmon caught annually near the mouth of the Amur are as follows (in thousands of individuals).

Odd Years		Even Years	
Year	*Number*	*Year*	*Number*
1907	1,478	1908	4,600
1909	2,950	1910	7,701
1911	3,856	1912	7,528
1913	7,469	1914	14,528
1915	994	1916	9,243
1917	557	1918	14,876
1919	420	1920	12,000
1921	200	1922	9,000
1923	18	1924	12,217
1925	0		

Pravdin's later data are given by weight. The following figures represent "thousands of centners" (a rough calculation on the basis of an average weight of 4 lb. per individual fish would give 27.5 fish per centner (= 50 kg.) and indicates that the 1926 catch was down to less than 5,000,000 fish).

Odd Years		Even Years	
Year	*Weight*	*Year*	*Weight*
		1926	171.5
1927	0	1928	116.5
1929	0	1930	73.2
1931	0.3	1932	75.49
1933	0.39	1934	53.4

The implications are that a very moderate preponderance of E fish became exaggerated by a slump which appeared in the offspring of the 1913 run. The decline in O fish continued for the next five generations by which time commercial production was nil. During this time the E fish continued to maintain themselves at a high level. Pravdin's figures for the ensuing nine years indicate that the catches of E fish declined during this period but with little revival of the O stocks.

This brief review of conditions obtaining in other parts of the geographic range of the species tends to confirm the impressions formed from a consideration of British Columbia data alone, namely, that a state of semi-equality of E and O stocks is usual and that extreme disparity, while it occurs in widely separated areas, is local and infrequent.

Changes in Abundance of E and O stocks

Figs. 3 and 4 show reported catches for various areas of the northern and central British Columbia coast over a period of approximately 20 years. Although, as stated previously, precise quantitative accuracy is not claimed for these records, the writer is confident that the direction of major changes in abundance is in general disclosed by these graphs.

Certain consistencies are apparent. In all areas except the north Queen Charlottes, where the O runs are practically nonexistent, each stock occupies a leading position at some time during the period shown. While changes in one stock appear to be independent of changes in the other stock, the direction of change in a given year is frequently similar in many areas. Thus, the E catches show a marked decline in all areas in 1932. Other even-year declines are apparent in nearly all areas in 1940 and 1946. Marked gains were registered in all areas south of the Skeena in 1944 and in all areas in 1948. The odd-year fish showed a decline in all areas except the Skeena in 1935 and heavy declines in all areas in 1941 and 1947. A widespread increase was shown in 1933; in 1939 all areas showed gains; in 1943 a very heavy increase occurred in all areas south of the Skeena, and in 1949 there was a substantial improvement everywhere.

These common tendencies suggest strongly that changes in abundance are frequently determined by factors which operate over relatively large regions.

Discussion

Reference is made again to the question how or why two populations with similar requirements and opportunities can continue to inhabit the same area on a totally different scale of numerical abundance.

The view that the smaller population is held down to a low level by

the existence of the larger population may be considered first. Certain points which appear to favour this view are:

1. Great disparity in the stocks of pink salmon is characteristic of the Fraser River system, where the "dominance" of certain sockeye stocks has also been conspicuous. The disparity in the latter species has

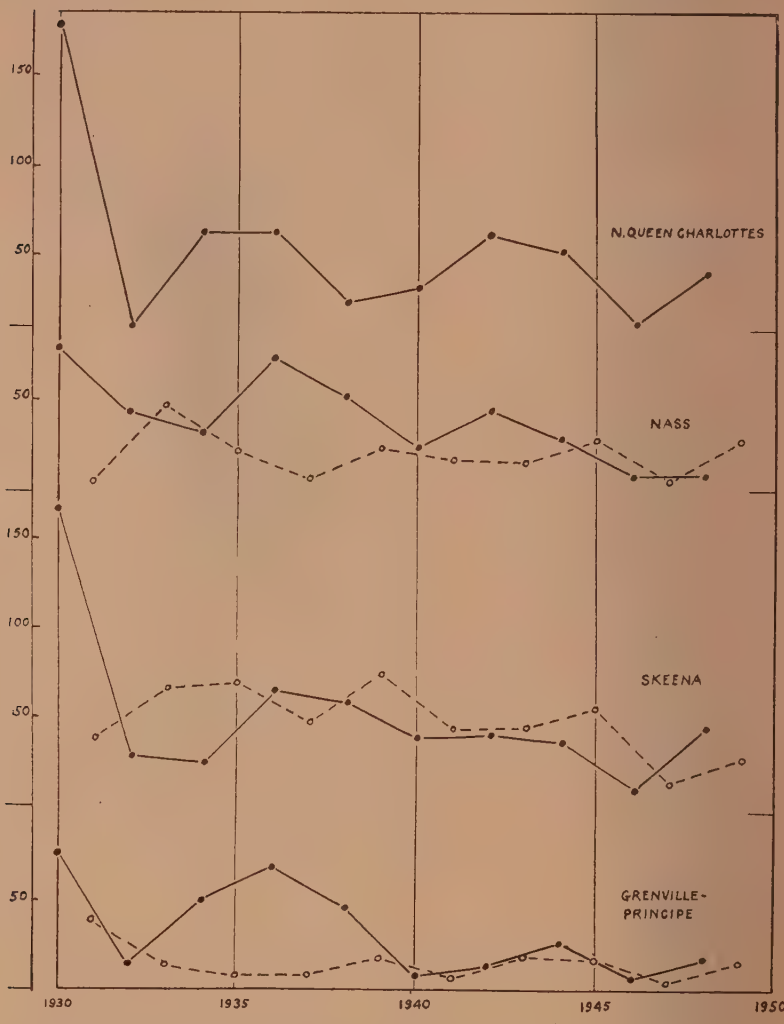

FIGURE 3.—Reported annual catches (thousands of cwt.) of pink salmon in areas of northern British Columbia. Solid line—E fish. Broken line—O fish.

been thought to be due to interaction between year-classes (Ricker, 1950) and it seems reasonable to seek a common explanation for the two species.

2. Attempts to establish "off-year" pink salmon runs in a stream possessing an abundant population of the other stock have been unsuccessful (Pritchard, 1938).

FIGURE 4.—Reported annual catches (thousands of cwt.) of pink salmon in areas of central British Columbia. Solid line—E fish. Broken line—O fish.

3. In the only documented instance of the inception of a state of extreme disparity in pink salmon (Amur River, see above), the decline of one population apparently synchronized with an increase in the other population.

Before presenting arguments which oppose this view, it may be pointed out that when two populations continue to exist at their respective levels (as seems, broadly speaking, to be the case in the Fraser system) each is being equally successful in reproducing itself. The smaller population is only being "held down" (relative to the larger one) if it is assumed that the higher population represents a more "natural" state to which the smaller stock should be approximating. The large population could in fact only be "holding down" the small one to its own reproductive rate. If, on the other hand, there are factors which tend to keep populations at or near their existing levels, continued disparity requires only an initial cause to keep it in being. In any case, it would seem that *production* of disparity is a different matter from its maintenance, since the former requires that the survival rates of the stocks be different whereas the latter requires that they be the same—that is, unless one stock is totally absent.

The view that the abundance of one stock inhibits the abundance of the other stock does not seem to be supported by the general geographic evidence already cited. Extreme disparity is exceptional (see Fig. 2). There are many regions, including such centres of abundance as southeast Alaska and central British Columbia, in which both stocks can show very high levels of population size. There is no evidence of a general reciprocal relationship between the size of E and O stocks. It is possible to cite examples which seem directly opposed to such an idea. For instance, the rise of the O stock to an extremely high level in 1943 in the Bella Bella, Bella Coola, and Rivers Inlet areas was followed by a marked increase in the E stocks of these areas in 1944 (Fig. 4). In the previously cited case of the establishment of a strong disparity in the Amur district, the initial decline of the O fish does indeed appear to have synchronized with an increase in the E stock. But if the available catch figures are accepted as indicative of the condition of the runs, the E population then remained nearly constant for a series of generations, whereas the O stock continued to dwindle with each successive life-cycle. The subsequent decline of the E stock in the years 1926 to 1934 seems to have elicited no such marked or rapid revival of the O fish as might be expected if this were the factor which was holding them down.

If, however, it is conceded that the general evidence concerning the independence of the two stocks is insufficient to exclude the possibility of interaction as a cause of continued disparity, it is necessary to con-

sider the periods in the life-cycle when such interaction might occur. In the case of the sockeye an explanation has been sought in terms of intraspecific competition or intraspecific predation during the rather lengthy period of lake residence. Since no such period occurs during the life-history of the pink salmon, no similar hypothesis can be set up for this species. There is in fact no overlapping between stocks at any stage of freshwater existence, and the only possibility of interaction in this medium would seem to lie in one stock rendering the habitat unsuitable in some way for the population of the following year. This possibility can be discounted in view of the very heavy pink salmon populations which do in fact occupy the same stream areas year after year in many parts of the geographic range of the species. Specific examples in British Columbia have been cited previously.

While evidence has been presented elsewhere (Davidson and Hutchinson, 1943; Neave, 1952) that pink salmon abundance tends to be determined by freshwater factors, the possibility that the condition of extreme disparity is maintained by interaction between E and O stocks in the ocean remains to be considered. On general grounds it seems rather unlikely that successive year-classes can establish such exclusive interrelations that they can determine their relative abundance without reference to the vast and varying numbers of other predators or competitors in the unrestricted environment of the sea. Other objections can also be raised.

Underyearling pink salmon, which from their numbers, distribution, and greater abundance in even years undoubtedly include many Fraser River fish, are to be found in the Strait of Georgia and among the San Juan Islands until July and early August (Foskett, 1951; Clemens, 1952). The fish of the other stock by this time have nearly completed their marine feeding period and are on their return journey to fresh water. They are concurrently contributing to the commercial fishery on the southwest and north coasts of Vancouver Island. If the same routes and depths are followed, the outward and inward migrations must be in close relation at some period, but it may be seriously doubted whether there is any prolonged feeding in common areas by different year-classes of fish which migrate extensively during such a relatively short period of marine life.

The view that continued disparity is the result of competition or predation between E and O populations seems to lead to the inference that in areas where both are abundant the stocks are not in contact at the appropriate period. The writer finds it difficult to think that there are a few special areas scattered within the wide range of the species wherein such contacts have been able to produce a continued eclipse of one stock

whereas in other areas the abundance of both seems entirely compatible. The difficulty becomes acute in the case of the Queen Charlotte Islands. Here it would have to be supposed that the marine phases of the O fish of a few streams are insulated from a form of predation or competition which imposes a continuous depression on the fish derived from nearby streams on all sides of them.

In seeking an alternative explanation for the occurrence of extreme and persistent disparity, the possibility might be considered that one stock has never been able to establish itself in certain areas. The apparently complete dichotomy of the species into E and O stocks is presumably a relatively recent event. The geographic areas suitable for pink salmon must have changed considerably during postglacial times. Once segregation into the two groups had been effected, colonization would be a separate process in each case and would not necessarily proceed at the same rates in all regions. The Queen Charlotte Islands might well present a difficult area for colonization from the mainland by a species with pronounced homing tendencies. The small area on these islands which is occupied by appreciable numbers of O fish might be interpreted as the bridgehead of an invasion which is now in progress. In the Fraser–Puget Sound area, which lies at or near the southern limit of the present distributional range, it might be argued that the E fish have arrived too recently to have encountered the specially favourable conditions necessary for a great expansion of population.

Such a theory would not account for the recently achieved disparity of the Amur River district. It must therefore be concluded that some and perhaps all cases of extreme disparity have been initiated by a different survival rate between stocks which were formerly on a more equal footing. As already pointed out, this different survival rate could not have persisted in cases where the two stocks are maintaining their relative positions and might indeed have been a very brief phenomenon.

In connection with Figs. 3 and 4, it has been noted that changes in abundance of pink salmon from one generation to the next are regional in their application. This is true also of the occurrence of extreme disparity. The latter may reasonably be thought to have been initiated by factors similar to those which induce the variations commonly seen in pink salmon stocks. These variations have been related to meteorological conditions affecting the freshwater phases of the life-history (Davidson and Hutchinson, 1943; Neave and Wickett, 1949; Neave, 1952). Such conditions can be regional in effect, and in a given year would affect only one stock. Factors which could adversely affect one stock in a regional manner include: droughts; heavy floods; unfavourable water temperatures; exposure and freezing of spawning grounds.

Increased survival is promoted by the maintenance of relatively constant water levels and favourable temperatures during the freshwater period. A mechanism evidently exists for initiating a difference in abundance between the E and O stocks.

Regarding the further development and fixation of disparity, the writer (Neave, 1952) has emphasized elsewhere the existence of factors which tend to confirm and exaggerate changes in population size, as well as factors which tend to promote stability. Attention was especially directed to the probable effect of predators during the migration of salmon fry to the sea, in inflicting relatively heavier losses on smaller populations. When a population exceeds or falls below certain limits of size it is likely to be subject to influences which tend to maintain the direction of change or at least to oppose a return to the former level.

The Amur data suggest that a disaster attending the reproduction of the 1913 spawning stock depressed the 1915 population to a point well below the levels recorded in previous generations. From this point the decline continued in each generation, resulting in commercial extinction in 1925 (of the escapement in that year Berg says "there were only single specimens that ascended small rivers falling into the Amur below Nikolayevsk"). The other stock maintained itself well during this period. It can hardly be supposed that good and bad reproductive seasons alternated regularly for 12 years. We must accordingly conclude that the initial catastrophe brought its own train of subsequent events. Conceivably, disparity could also result from an *increase* of one stock. Given an exceptionally favourable reproductive season, a population might "break through" the existing predator control and attain a relatively permanent high level of abundance. To attain extreme disparity in this way, however, the process would have to start from a relatively low level of the stocks, since limitations of habitat other than predators would certainly stop expansion at some point.

It is not necessary to assume that a major downward change inevitably proceeds to the extreme degree shown in the case of the Amur. Stabilization might occur at some relatively low level at which the young fish begin to be less available to predators and the reproductive efficiency of the population is higher than that of a large population. The evidence indicates that pink salmon populations can be stabilized (relatively speaking) at various levels, at least when in different localities. The Amur case does suggest strongly, however, that between a high status and a low status there may be intermediate levels of abundance which are very difficult to maintain under natural conditions. In cases where disparity has become acute, chances of a small population attaining the status of the large one may be very small.

Extreme, persistent disparity is a rare condition in pink salmon. Apparently the limits within which the populations can change without being definitely committed to a new status are broad enough to permit very considerable fluctuations and are only transcended under highly exceptional and infrequent circumstances.

Those who are interested in the practical problem of promoting large pink salmon runs in "off" years should consider the possibility that a gradual increase of the existing stocks or the planting of a few hundred thousand eggs to start a new population may frequently not be a feasible approach to the problem unless supplementary measures are taken. On the other hand they can derive satisfaction from the observed fact that large as well as small or negligible populations can exist in many waters, and from the evidence that the two states are not reciprocal. Present knowledge suggests that the change from a low to a high status should be made as far as possible in one "jump," or that the factors (believed to be especially the removal of fry-migrants by predators) hindering a more gradual increase should be eliminated.

Acknowledgment

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Numerical Relations Between Abundance of Predators and Survival of Prey

by

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There is growing interest in control of predators as a tool in fishery management. Assessments of its usefulness will come only from repeated trials under varied conditions. A relatively small number of situations have already been examined. Some have given negative results; others show much promise. Even though the final answer must come from an actual trial, there are some simple theoretical considerations which will assist in assessing in advance the prospects of success. Used intelligently, they will help in selecting predation situations where control seems likely to be of real value.

Three Types of Predation

It is convenient to distinguish three types of numerical relationship between predators and a species of prey which they attack.

A. Predators of any given abundance take a fixed number of the prey species during the time they are in contact, enough to satiate them. The surplus prey escapes.

B. Predators at any given abundance take a fixed fraction of prey species present, as though there were captures at random encounters.

C. Predators take all the individuals of the prey species that are present, in excess of a certain minimum number. This minimum may be determined in different ways: (1) There may be only a limited number of secure habitable places in the environment, so that some prey are forced to live in exposed situations where capture is inevitable. The number of such secure niches may be partly governed by territorial behaviour of the prey. (2) The maximum "safe" density of prey may be the one at which predators no longer find it sufficiently rewarding to forage for them, and move to other feeding grounds.

The three situations above tend to intergrade, of course, but it is useful to keep their differences in mind.

Situation A

This is likely to occur when a prey species is temporarily massed in unusual numbers, for example, adult herring in spawning schools, or newly-emerged fry of pink and chum salmon going downstream. The main characteristic of such situations is that the number of prey eaten depends on the abundance of predators, but not on the abundance of prey. Hence such situations cannot last long, and the predators cannot make the prey in question their principal yearly food; otherwise they would almost surely increase in abundance and the situation would change to type B or type C. If a type A situation persisted for long, it would come to an abrupt end with the extermination of the prey.

Situation B

Here the number of the prey species eaten is proportional to the abundance of predators and to the abundance of prey. Unlike A, this type of predation can easily

occur over long portions of the year; and the prey species may comprise the larger portion of the predators' annual ration. This situation was observed at Cultus Lake, British Columbia, for predation of squawfish, char, coho and trout upon fingerling sockeye, over a wide range of abundance of the latter (Foerster and Ricker, 1941).

Situation C

The classical example of this situation was described by Errington for bob-white in Iowa, where a given range would winter safely a fixed number of birds, practically independently of the number which were present in autumn, the surplus being taken by predators. Studies conducted from the Atlantic Biological Station of the Fisheries Research Board of Canada, St. Andrews, N.B., suggest that in some rivers predation upon Atlantic salmon parr tends toward type C, because a marked increase in the number of young fish planted was followed by only a relatively small increase in number of surviving smolts (Elson, 1950). In type C situations the predators must tend to have ample alternative foods, and they are often mobile so that they can leave an area where the food supply has been "cleaned up" for the season.

Relation of Abundance of Predators to Mortality Rate and Survival Rate in "Type B" Situations

Consider a prey species which is subject to type B predation over some part of its life history. Assume first that predation causes the whole of the mortality that the prey is subject to during that period. Then the prey species decreases in abundance according to the well-known exponential formula

$$N/N_o = e^{-it}, \qquad (1)$$

where: N_o is initial abundance, N is abundance at time t, $e = 2{\cdot}718\ldots$, and i is a statistic representing the fraction of the prey which would be eaten in a unit of time if its abundance were held constant for that long; i is often called the instantaneous mortality rate.

Under the conditions postulated, instantaneous mortality rate is directly proportional to the abundance of predators. This can be illustrated by considering a situation where predators attack a prey population of 1,000,000 individuals under type B conditions, and they inflict losses corresponding to $i = 0{\cdot}8$, where the unit of time, t, is the whole season that predator and prey are in contact. Equation (1) indicates that in, for example, 1/1000 of the season, the predators will eat $i/1000 = 0.0008$ of the prey present, or 800 fish. During the next thousandth of the season, the predators eat $i/1000$ of the surviving prey, or $999{,}200 \times i/1000 = 799$ fish. The following interval they eat $998{,}401 \times i/1000 = 799$; then $997{,}602 \times i/1000 = 798$. This continues until all the thousand time-intervals have elapsed, at the end of which there are:

$$1{,}000{,}000(1 - 0{\cdot}0008)^{1000} = 472{,}400$$

survivors, or 47·2 per cent. What happens if the number of predators is doubled? In that event, during the first thousandth of the season twice as many fish will be eaten, i.e. 1,600, leaving 998,400. In the next thousandth the fraction eaten is likewise double, namely 0·0016; multiplied by the number of survivors this gives 1,597; and so on. At the end of the season $1{,}000{,}000(1 - 0{\cdot}0016)^{1000}$ survive, which is 201,900, or 20·2 per cent.

Thus doubling the number of predators doubles the instantaneous mortality rate (which is true generally), but it increases actual mortality by only 27·0/52·8 = 51 per cent (which is true of only this particular example).

The general relation between predator abundance and actual mortality, or survival, is most conveniently expressed as:

$$\frac{p_2}{p_1} = \frac{\log s_2}{\log s_1}, \qquad (2)$$

where p_2 and p_1 represent two levels of predator abundance, and s_2 and s_1 are the corresponding survival rates for the prey. This expression can easily be derived from (1), since p is proportional to i, and $s = N/N_o$ when $t = 1$.

Formula (2) indicates that survival does not change in a simple inverse relation to number of predators. For example, in a situation where predators have been reduced to half ($p_2/p_1 = 1/2$), some typical values are shown below:

Original survival rate (s_1, as %)	Ratio of new to old survival rate (s_2/s_1)
0·01	100·
0·1	31·5
1	10·0
5	4·46
10	3·15
25	2·00
50	1·41
90	1·05
100	1·00

Schedules like this make it possible to estimate the beneficial effect of any given degree of predator reduction for type B situations. The principal lesson they teach is that predator control is more likely to be economically successful when survival rate is small to begin with (over the span of the prey's life history on which the predators in question operate). An easy assumption might have been that, by halving a predator population, we should double the survival of the prey. As matters actually stand, this much benefit will be gained only if mortality from predation is at least 75 per cent in the beginning ($s_1 = 25$ per cent). However if the initial mortality rate is greater than 75 per cent, then reducing the predators by half will more than double the number of survivors.

As a matter of fact, when mortality is initially great and survival small, quite startling improvements in survival can be achieved by means of very moderate reductions in predator population. Again using formula (2), we obtain the schedule below:

Original survival rate	Reduction in predators necessary to double survival rate
0·01%	7·5%
0·1	10·0
1	15·0
5	23·2
10	30·1
25	50·0
50	100

Presented in this manner, it is encouraging to discover that when survival is in the "medium" range from 1 to 10 per cent, it requires a reduction of predators by only one-third or less in order to achieve important benefits. This, in fact, is the range involved in Canadian attempts at increasing salmon production by predator control. In the sockeye salmon experiment mentioned earlier, the investigators were at first surprised at the magnitude of the improvement effected by quite a moderate decrease in predator abundance. However, this can have a discouraging as well as an encouraging aspect. For if a small decrease in predators results in important gains, then, equally, those gains can be wiped out by a subsequent small increase in predators, which might come from improved survival conditions for the young of the predators themselves.

Another general principle illustrated by the schedule above is that great fecundity is apt to be accompanied by a natural instability in population size, and particularly by marked variation in year-class strength. For example fish like the cod, which produce pelagic eggs to the number of 1,000,000 or so per female, may easily suffer average predation losses of the order of 99·9 per cent during their development and larval life. At that level, a 10 per cent decrease in abundance of predators causes a 100 per cent increase in strength of the year-class at the end of larval life.

The relationships above apply of course only when the whole of the prey's mortality is caused by predation. To the extent that other causes enter the picture, any given reduction in number of predators has less effect in increasing survival.

Control of Predators in Situations of Types "A" and "C"

The considerations developed above for type B situations apply equally to type A. There is an apparent difference arising from the fact that whereas, with type B, survival rate (s) is invariable from year to year for any given abundance of predators, in type A survival rate varies with abundance of prey. However, this does not change the nature of the effect which any given reduction of predators will have upon survival. Equation (2) will apply, whatever numerical value of s would be anticipated at the level of prey abundance existing in any particular year.

In type C situations, obviously the mathematical relations above do not apply at all, as long as they remain type C. The definition of C implies that changes in abundance of predators have no effect upon survival of prey; and for predator control to become effective it must first reduce the predators to the point where predation begins to change toward type B. This may be entirely feasible. In Elson's Pollett River experiment, removal of mergansers and kingfishers by shooting was sufficiently thorough to increase the survival from a heavy planting of young salmon four- or five-fold. This must mean that the predation situation had been changed; from one close to type C, it became type B or even type A, for whatever few birds managed to hang on or occasionally wandered into the area.

If we look at predation from the point of view of the predator rather than the prey, a broad distinction can be drawn between the warm-blooded and the cold-blooded carnivores. The former have a fairly constant food requirement, and hence are more likely to become involved in predation situations of types A or C. The great mobility of birds, and to a less extent of mammals, enables them to move quickly to localities where food is temporarily abundant (type A situations). At the same time they require a steady food intake to maintain body temperature and will quickly

leave an area where food abundance is depressed so far that foraging does not provide their minimum needs (thus creating type C situations). Predaceous fishes, by contrast, have a much lower minimum ration per unit body-weight, and much greater flexibility in the amount of food they can consume and still live normal lives. Many of them must set up type B situations, in which they can take whatever food they encounter as often as they encounter it, and rarely find prey so abundant that any must be refused.

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Fertilization and Predator Control to Improve Trout Production in Crecy Lake, New Brunswick

by

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A study conducted over a number of years on eight Charlotte County lakes, of which Crecy is one, showed that the annual yield of trout (*Salvelinus fontinalis*) to the anglers averaged only 0·58 pounds per acre, and that introduced hatchery trout contributed little to this low yield (Smith, 1952). By virtue of drainage from an area of non-productive soils, the supply of nutrient salts in the waters of these lakes is poor. The infertility of the waters is viewed as a primary and obviously important factor in determining the low yields of trout.

The extent to which the yield of trout to anglers might be improved by overcoming, even if temporarily, the deficiency in the supply of nutrient salts by means of artificial fertilization has been explored at Crecy Lake. In the course of the investigation there was evidence that beneficial effects of the fertilization upon the yield of trout were being masked by bird, mammal and possibly eel predation. Apparently such predators of fish as the loon, kingfisher, otter and others were being attracted to Crecy Lake by a consistent annual stocking with trout which provided as good, if not better, fishing than found by these predators in neighbouring lakes. These observations led to an extension of the Crecy Lake programme on fertilization to include measures of predator control.

This article is preliminary in character. An account of the effects of fertilization upon the limnological conditions in general and a more complete presentation of the action of the fertilization and predator control upon the yield of trout in particular will be presented at a later date. Other preliminary reports have already been published (Smith, 1948a, b).

Crecy is a headwater lake on the Bocabec River system, Charlotte County, southwestern New Brunswick. It has an area of 50·4 acres (20·4 hectares) and a mean depth of 7·8 feet (2·4 metres). Since the maximum depth is only 12·5 feet (3·8 metres), the waters of the lake are subject to mixing throughout by winds of even moderate velocity. The lake has a volume of $17 \cdot 18 \times 10^6$ cubic feet ($0 \cdot 49 \times 10^6$ cubic metres). Additional limnological data for this lake may be found in a previous publication (Smith, 1952).

Actions Taken

1. *Annual Creel Census*

A man has been stationed on the lake for this purpose during each angling season since 1943 with the exception of 1945 when the lake was closed to fishermen. Data have been obtained upon the number of marked and unmarked trout killed, the number of anglers, the time spent in angling whether trout were taken or not, and the length, weight and sex of the fish. Almost all fishing has been from boats that landed at one point, which arrangement has favoured a thorough census.

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2. Stocking with hatchery-reared trout

Since the stock of native trout in the lake was limited, additional trout were introduced to assure as complete utilization as possible of any improved trout-producing capacity that might result from the fertilization. Yearling trout, marked by fin-clipping, were planted in 1944 and 1945, and both marked yearlings and fingerlings thereafter annually. The hatchery trout have been planted sufficiently late in the season so that they have not been subject to angling until the following year. These trout have been supplied by the Fish Culture Development branch of the Department of Fisheries of Canada from the hatchery establishment at Saint John, N.B.

3. Fertilization of the lake

On June 19 and 20, 1946, one ton of ammonium phosphate fertilizer (11-48-0) and 500 pounds of potassium chloride (60 per cent K_2O) were spread over the surface of Crecy Lake, principally over the littoral areas. The application amounted to 6·5 pounds of the fertilizers per acre-foot, or 0·39 mg. of phosphorus (P), 0·21 mg. of nitrogen (N) and 0·27 mg. of potassium (K) per litre of water. The total phosphorus (P) content of the water just prior to fertilization averaged 0·016 mg. per litre. The fertilizers were donated by the New Brunswick Resources and Development Board.

4. Erection of fish barrier and trap in outlet of lake

Of the yearling trout (675) planted in Crecy Lake in the late fall of 1944, anglers captured 12 individuals during the following season in a small pond on the outlet of the lake. When the yield of trout fell off markedly in 1948 (Table I), movement of planted trout from the lake was considered as a possible factor contributing to the decline. To obviate this factor a fence of galvanized wire ($\frac{3}{8}$-inch mesh) was placed across the outlet immediately below the lake in July, 1948, before the annual stocking was made. A year later a trap was incorporated into the barrier to assess the number of trout that might attempt to leave the lake. The fence and trap have been maintained effectively throughout all seasons of the year.

Only nine yearlings and one fingerling of the stock planted in 1949 attempted to run from the lake. Of the introductions made in 1950, 2·5 per cent of the fingerlings (168) and 6·1 per cent of the yearlings (41) were taken in the trap. These observations suggest that migration from the lake was not a prominent factor in the disappearance of the planted trout before the barrier was erected. It is pertinent that the yield of trout continued to decline in 1949 (Table I) although escape of trout from the lake was prevented.

5. Control of fish-eating birds and mammals

The diminishing yield of trout to the anglers from 1947 to 1949 was associated with an increase in the number of visits made to the lake by fish-eating birds and mammals. Attempts to curtail the activities of these predators were initiated in early August, 1949. Control measures have consisted of shooting and trapping under permit as many predators as possible and, failing this, frightening them from the lake, in either case before they have had the opportunity to feed. The control has increased in effectiveness with time. To be as effective as it has been, constant attention has been required from a technician resident on the lake.

6. Trapping of eels in the lake

The capture of 897 eels in the trap in the outlet during the fall of 1949 disclosed a greater abundance of these fish in Crecy Lake than was formerly appreciated. (A good proportion of these eels would doubtless have left the lake in 1948 if they had not been prevented from so doing by the fence.) The eel is the only piscivorous fish in the lake aside from the trout. To determine if their number could be reduced appreciably and thereby the control of trout predators extended, a programme of trapping eels in baited traps set in the lake was begun in 1950. The numbers of eels taken in this manner were 369 in 1950 and 78 in 1951. These captures, although they comprised quite large numbers when consideration is given to the size of Crecy Lake, by no means depleted the stock of eels in the lake. This is shown by the following numbers of eels which were taken in the outlet trap when they attempted to migrate: 105 during the fall of 1950; 55 during April, 1951; 357 during the fall of 1951. The eel is catadromous, and limnetic populations of the species are primarily recruited from the elvers that annually enter fresh waters from the sea; accordingly the best eel control would be to prevent the entrance of the young into the lake. A barrier dam was erected in the outlet in the spring of 1951 with this objective. The efficacy of the measure has not yet been demonstrated and in any case its action has no bearing upon the data presented here.

Results of Fertilization

The yield of trout and the rate of their capture from Crecy Lake were appreciably greater in 1947, the year following fertilization, than had been experienced previously (Table I). Much of the improved yield may be ascribed to the excellent growth made by the introduced fingerlings. From September, 1946, to May and June, 1947, these trout increased in mean fork length from 3·2 to 8·5 inches (8·2 to 21·7 cm.) and were accordingly a suitable size for angling when yearlings (Table III). Of the 425 trout taken in 1947 by the anglers, 254 (60 per cent) were from this planting.

Since no marked fingerlings were introduced into Crecy Lake prior to 1946, a direct comparison of the growth rate of this size of stock before and after fertilization is not possible. There is good evidence, however, that the fertilization resulted in a decidedly faster growth rate by the fingerlings than would have been realized normally.

Table I

Yield of trout to anglers from Crecy Lake

Year	Number caught	Number per rod-hour	Pounds per acre	Kilograms per hectare
1943	166	0·45	2·2	2·5
1944	148	0·5	1·45	1·6
1946	139	0·6	1·4	1·6
1947	425	1·0	3·55	4·0
1948	110	0·3	1·6	1·8
1949	39	0·15	0·9	1·0
1950	264	0·6	2·9	3·2
1951	1,441	1·4	6·4	7·2

Table II

Percentage survival of planted trout to anglers' creels

Year planted	Stock	Number planted	Number subsequently caught	Per cent survival to anglers
1944	yearlings	675	6*	0·9
1945	yearlings	812	83	10·2
1946	yearlings	659	111	16·8
1946	fingerlings	6,701	286	4·3
1947	yearlings	675	26	3·85
1947	fingerlings	6,684	52	0·8
1948	yearlings	675	12	1·8
1948	fingerlings	6,575	5	<0·1
1949	yearlings	674	201	29·8
1949	fingerlings	6,633	129	1·9
1950	yearlings	675	306	45·3**
1950	fingerlings	6,750	1,333	19·7**

**12 additional individuals were taken from pond on outlet of Crecy Lake.*
***to June 16, 1952.*

Fingerlings from the same hatchery stock that was planted in Crecy Lake in 1946 were also introduced during that year into Gibson Lake, which lies in the same area of Charlotte County and in many respects of morphology and character of water is similar to the former lake. Gibson Lake was not fertilized and there the growth in length of the introduced fingerlings from August, 1946, to May, 1947, was only from 2·9 to 4·4 inches (7·4 to 11·1 cm.). It is also significant that no yearlings were found among the 453 trout taken from Crecy Lake by the anglers in 1943, 1944 and 1946, before fertilization. The assumption is made that, as yearlings, trout were not large enough to be taken, or if taken were not retained by the anglers. This situation was found to obtain generally in Charlotte County lakes (Smith, 1952).

An improvement in the growth of trout planted as yearlings also followed the fertilization (Table III). However, the improved growth rate by the planted fingerlings to the point that they were of suitable angling size during the year following their introduction is considered the more important result of the procedure. Introductions of hatchery trout to overcome deficiencies in stocks of native fish is most economical when good returns to the anglers are realized from planting fingerlings. It develops all too frequently, however, that because of various adverse conditions the survival of planted fingerlings to fishermen's creels is discouragingly poor. Recourse may be had to rearing the trout to angling size under artificial conditions before distribution on what is largely a put-and-take basis, relegating the natural aquatic environment to a holding rather than a producing area. The fertilization of Crecy Lake resulted in a sufficiently better growth of fingerling trout to shorten appreciably the period during which they were subject to natural mortalities before being cropped by the anglers. Of the fingerlings planted in 1946, 4·3 per cent were subsequently captured by the fishermen. This percentage in itself is small but viewed as a survival of planted fingerlings to anglers' catches is noteworthy for waters of the area, as well as elsewhere (Shetter, 1939; Smith, 1952).

Table III

Growth of planted trout

Stock and year of planting		Mean fork length in centimetres (Number in sample in brackets)				
		When planted	When angled 1st year after planting	Increment in one year	When angled 2nd year after planting	Increment in two years
Yearlings.....	1944	28·3±1·79 (41)	— *		31·2 (5)	2·9
	1945	19·2±2·19 (77)	25·6±1·63 (66)	6·4	32·3±2·10 (12)	13·1
	1946	21·3±1·54 (108)	28·9±1·27 (111)	7·6	—**	
	1947	21·4±1·61 (53)	31·0±1·92 (26)	9·6	—**	
	1948	16·2±1·30 (60)	30·2±3·46 (11)	14·0	—**	
	1949	18·7±1·82 (60)	26·8±1·71 (181)	8·1	36·5 (7)	17·8
	1950	18·5±1·83 (239)	25·0±2·45 (278)	6·5	32·7 (2)	14·2
Fingerlings.....	1946	8·2±1·09 (49)	21·7±1·30 (244)	13·5	32·4±1·87 (25)	24·2
	1947	7·4±0·95 (76)	23·5±1·95 (32)	16·1	33·3±1·67 (15)	25·9
	1948	6·1±0·84 (175)	21·4±1·95 (23)	15·3	30·6 (2)	24·5
	1949	6·6±0·79 (67)	19·0±2·16 (60)	12·4	25·9±3·09 (68)	19·3
	1950	8·4±1·29 (55)	17·0±2·06 (905)	8·6	23·3±2·51 (287)	14·9

Lake not open to angling in 1945.
**None captured.*

Results of Predator Control

The better yield of trout to anglers which was realized in 1947 did not persist, and in 1948 and 1949 the anglers' catches fell off markedly to below pre-fertilization levels (Table I). The survival of both the planted fingerlings and yearlings to the anglers was poor (Table II). (There was evidence from gill-netting and from the carry-over of planted trout into the second year from their introduction that the poorer yields in 1948 and 1949 reflected correspondingly lower trout populations in the lake.) Yet as may be seen in Table III, the growth of the fewer trout captured by the anglers was good, for the most part an improvement over those taken in 1947. The beneficial effects of the fertilization were no doubt still being experienced, but also contributary to the continuing fast growth of the trout was less competition for a common food supply.

As we have already noted, the declining yields of trout in 1948 and 1949 were associated with an increased predation by fish-eating birds and mammals, and perhaps by eels as well. Attempts at predator control, which these observations prompted, were begun in 1949 and the first stocks of planted trout that could have been affected appreciably were those introduced into the lake in that year and initially subjected to angling in 1950. It is shown in Table II that a greater percentage of these trout, especially those planted as yearlings, survived to the anglers' creels. With a continuance of bird and mammal control at a more effective level and extension of the programme to the trapping of eels on the lake in 1950, still better results were obtained with respect to both survival and yield of hatchery trout. Of the yearlings put into the lake in 1950, 45·3 per cent were subsequently taken by the anglers (Table II). We consider it more noteworthy, however, that 19·7 per cent of the fingerling stock survived to the fishermen.

Coincident with a greater survival of planted trout, the growth rate was depressed (Table III). It would appear that a condition of over-population had almost been reached—over-population from the viewpoint of the desirability of having planted fingerlings attain a suitable size for angling during the next year, i.e. as yearlings.

Discussion

However effective fertilization may prove to be as a procedure to improve trout production in natural lakes in certain situations, there are difficulties and definite limitations to its general application.

1. Fertilization is obviously of no value if applied to a lake that presents an adverse chemical environment for trout.

2. So far as we can visualize at the present time the cost of the fertilizer limits the size of the lake that can be treated, even if there were assurance that a given dosage would result in an improved trout production. Interpretation of what is a reasonable cost is subject to a divergence of opinion, but it should be borne in mind that we are primarily concerned with a sport fishery whose value cannot be gauged by the worth of the fish as food.

3. Unwanted fish in a trout lake will also benefit from any increase in the fish-producing capacity. On the one hand there are species that are competitors and predators of trout and, on the other, forage fish that are trout foods. In many Maritime lakes yellow (*Perca flavescens*) and white (*Morone americana*) perch, eels (*Anguilla rostrata*) and certain other species are inimical to trout. Control of such fish is indicated in order to realize at all fully the beneficial effects upon trout production that may accrue from artificial fertilization.

4. A sufficient supply of young trout to capitalize upon a higher productive level after fertilization is prerequisite. Where because of poor spawning facilities young native trout are scarce, transplantations from other waters or plantings from hatchery stocks are required and may on occasion present difficulties.

5. Fertilization to be effective implies creating or intensifying a condition of eutrophy, even if no more than temporarily. Blooms of phytoplankton occur where they have not previously been noted (Smith, 1948; Langford, 1950). Decomposition of the increased amounts of organic matter increases or causes hypolimnial deficits in

dissolved oxygen and depressions of winter values at all levels when lakes are ice-bound. A marked reduction in the amount of dissolved oxygen may be helpful to the phosphorus exchange in some lakes by presenting conditions suitable for the reduction of ferric to the more soluble ferrous phosphate (Einsele, 1938; Hayes, 1951), but this is no compensation for depletion of oxygen to the point that fish are killed. Almost complete winter-kills of fish were experienced in fertilized lakes in Michigan (Ball, 1950). However, at Crecy Lake the mean dissolved oxygen content was reduced to a low of only 6·8 ml. per litre (71 per cent saturation) during the winter following the fertilization. A greater but yet not severe deficit was found two years later at the end of a winter season with greater ice and snow cover on the lake. On March 29, 1949, the mean content was 5·8 ml. per litre (62 per cent saturation). Fertilization to attain maximum eutrophication without too serious reduction in dissolved oxygen is a nice manipulation of the limnetic environment which is certainly not yet fixed by prescription.

Physical difficulties involved in patrol and costs, increasing with increasing size of lake, present the most serious limitations to control of fish-eating birds and mammals. However, something quite short of complete control may prove worthwhile. Our experience at Crecy Lake demonstrated that to approach complete control close attention was required, and that patrol on the ordinary workaday basis would have been ineffective since so many of the predators visited the lake in the early daylight hours and to a lesser extent in the evening.

A scientific permit is required to destroy throughout the year those fish-eating birds that come under the protection of the Migratory Birds Convention Act.

Conclusion

Notwithstanding the considerable number of technical and biological problems involved in the development and practical application of artificial fertilization and predator control as means of improving trout angling in natural lakes, the results obtained at Crecy Lake are encouraging. The improvements in the anglers' catches of trout that followed both fertilization and predator control on that lake are sufficiently clear-cut to warrant further application in other similar non-productive waters.

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